State of California

THE RESOURCES AGENCY

Department of Water Resources

BULLETIN No. 164

TEHACHAPI CROSSING DESIGN STUDIES

Book V

AUGUST 1965

HUGO FISHER
Administrator
The Resources Agency

EDMUND G. BROWN
Governor
State of California

WILLIAM E. WARNE
Director
Department of Water Resources

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Book V

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: 1. Mr. H. G. Dewey, Jr.
2. Mr. Alfred R. Golze'

Date : May 10, 1965

File No.:

Subject: Tehachapi Pump Lift System

Donald P. Thayer
: Department of Water Resources

In a letter addressed to the Chief Engineer dated May 8, 1965, the Tehachapi Crossing Consulting Board gave a reply to the questions asked of them at their meeting on May 3 through May 8, 1965. The Board's reply is unusually complete and little can be added to it; however, in the following paragraphs I will present an analysis of it and append my recommendations for your action pursuant thereto. A copy of the Board's letter is attached.

In their reply, the Board recommends that no further consideration be given to the Pastoria Creek Route for the Tehachapi Pumping Lift. Detailed basis therefor was not given in their report but in lieu thereof they cited the report of the Consulting Board for Earthquake Analysis, dated April 8, 1965, and the exploration conducted by the Department and reported in the report entitled Report on Tehachapi Alternative Lift Systems dated April 1965. As a corollary to this recommendation, the Board recommended that further design efforts of the Department be directed to a pumping lift along the Ridge Route.

In commenting on the pumps to be used for the Tehachapi Lift, the Board states as their conclusion that entirely adequate and reliable pumps for either the one-lift scheme or the two-lift scheme can be designed and built. In support of this they quote from the report by Daniel, Mann, Johnson, and Mendenhall, entitled

NAME (REV. 4-62)	Thayer 5/10/65	Dewey 5/10/65	

Tehachapi Pumping Facility, California State Water Project Research and Development Program, April 1965. They also quote presentation made by Professor Gerber before the Board on April 5, 1965, entitled Additional Remarks on European Pumping Practices by Professor Hans Gerber, Swiss Federal Institute of Technology. In addition to this they cite the statements made before them by Professor Neal of the Alden Hydraulics Laboratory, Worcester, Massachusetts, concerning the tests being carried on at the National Engineering Laboratories in Scotland for the Bechtel Corporation. These tests, conducted at independent laboratories, closely confirm the results of the model manufacturers' tests which largely have formed the basis of preliminary selection of the pumps to be used. Supplementing and confirming these tests are preliminary results obtained from tests performed for the Department in two manufacturers' laboratories in Europe. In addition, they cited statements confirming their conclusions made by pump designers in the three principle European manufacturers. By this finding the Board confirms our position that the route selection is not dependent upon the potential availability of any particular type of pump.

Commenting on the estimated costs of the various alternatives considered, the Board found that the greatest variation in initial capital cost of the various plans was about 12 percent. They commented that this is probably within the estimating error; hence, for all practical purposes, the various schemes might be considered equal in cost.

The Board considered the matter of reliability at some length. In the first place, they felt that the greatest reliability would be in a surface pumping plant, in contradistinction to an underground plant. Next, they concluded that the greatest security would be secured by discharge lines in tunnels. Finally, the Board found that the greatest reliability would be achieved by a single pumping plant. In this latter connection they mentioned seven different considerations and found that in each the single plant offered equal or greater reliability than in the two-lift concept. This finding closely parallels the quantative reliability study made by DMJM and presented in Volume II, Part B of the report referred to above.

In conclusion, the Board recommends that the Department proceed with design of a single lift Tehachapi pumping system along the Ridge Route. They stated that in their opinion an efficient, reliable, and secure pumping system could be designed and constructed accordingly.

Although not a part of their formal report, the Board informally took cognizance of the recommendations of the Consulting Board for Earthquake Analysis that Syphon No. 2, between tunnels 2 and 3, of the Ridge Route Alignment, be modified to eliminate it entirely or at the least greatly reduce the head on it. In this connection, they suggested the possibility of constructing a fill of rock spoil from tunnel excavation across this canyon to support the syphon and reduce the head to something possibly in the order of 100 feet, or eliminate it entirely.

With the disposition of the various alternatives, the design staff will be able to devote full attention to the design problems, all of which are susceptible of solution according to established precedent. Among the most important of these the following may be enumerated:

1. Motor Starting: It is recognized that direct, full voltage starting of motors for the Tehachapi Pumping Lift would impose unusual and difficult problems in the design of the electrical machines and it is recommended that such an idea be abandoned. There are at least three alternatives which may be considered.

a. Reduced voltage starting.

b. Synchronous starting, back-to-back, with a hydraulically driven generator of sufficient power to bring the pump motor to synchronous speed with zero pump discharge.

c. The same as described in subparagraph b, but with an electrically driven generator.

2. Pump Design and Testing: The pump model testing program now underway should be continued with the greatest emphasis being placed upon the model of the four-stage pump being considered for the single lift system. The tests of the other two models should be continued and brought to a satisfactory conclusion. You have, from time to time, expressed interest of the possibility of utilizing a five-stage pump for the single Tehachapi Lift. Although, at the moment, this does not appear to me to have any advantage, it will be made the subject of a design study and will be reported to you separately.

3. Syphon No. 2: In accordance with the informal discussion with the Board and with the recommendations of the Consulting Board for Earthquake Analysis, studies will be initiated immediately toward realigning the tunnel route to eliminate or minimize this syphon.

4. Discharge Lines: For reasons of security against seismic damage, the Board has recommended that prime consideration be given to underground discharge lines located in tunnels. While I had originally favored surface discharge lines for the purpose of simplifying construction and obtaining what I believed to be a more adequate piece of construction, final design studies of the tunnel discharge lines will be made. Special attention will be given to design of the bifurcation or manifolds. Effort will be made to formulate a design which will, if possible, avoid the use of quenched and tempered steel for the discharge line.

Recommendations: In view of the foregoing, I recommend that the following actions be taken immediately upon your approval hereof:

1. The single lift plan generally along the Ridge Route as now delineated be adopted for the Tehachapi pumping lift.

2. The tunnel alignment be modified to eliminate or at least greatly minimize Syphon No. 2.

3. Further design studies of underground versus surface discharge lines be made with a subsequent recommendation to you as to the design to be finally adopted.

4. The present model testing program be continued to a conclusion with special emphasis on the model of the four-stage pump which has been tentatively selected for the single-lift scheme.

5. Studies be made of the desirability of considering a five-stage pump for the single lift plan.

6. The design of the approach canal and forebay for the Tehachapi Pumping Plant be completed and the work be placed under contract at the earliest possible date.

7. A detailed report for the record, along the lines you previously directed, be prepared.

APPROVED: Recommendations 2, 3, 5 and 7 approved. Approval withheld on recommendations 1, 4 and 6 to permit MWD additional time to study data.

Alfred R. Golze'
Chief Engineer

Date MAY 12 1965

MINUTES OF MEETING
WITH ENGINEERING COMMITTEE
OF THE
BOARD OF DIRECTORS
OF
THE METROPOLITAN WATER DISTRICT OF SOUTHERN CALIFORNIA

Los Angeles, California
May 20, 1965

On May 20, 1965, a meeting was held at the offices of the Metropolitan Water District for the purpose of presenting a status report by Mr. A. R. Golze', Chief Engineer of the Department of Water Resources, on Tehachapi Crossing planning. The meeting was held under the auspices of the Engineering Committee of the Board of Directors of the Metropolitan Water District. Those present at the meeting are listed below:

Metropolitan Water District

R. A. Skinner
W. C. Farquhar
W. A. Burler
J. Jensen
W. S. Peterson
A. F. Bush
L. E. Cramer
D. C. Brooks
E. T. Ibbetson
J. Lauten
A. J. Williams
W. P. Winn
M. M. Anderson
G. W. Smith
H. J. Mills
E. W. Rockwell
R. B. Diemer
J. M. Davenport
L. L. Aufdenkamp
H. V. Crawshaw
H. Boylan
F. Vachon
E. L. Grubb
A. F. Monteverde
M. G. Smedegaard

Department of Water Resources

A. R. Golze'
D. P. Thayer
J. A. Wineland
J. J. Doody
K. G. Wilkes
L. H. Tuthill

Daniel, Mann, Johnson and Mendenhall

H. Gartmann
D. R. Miller

Mr. Golze' introduced the Department personnel, and then presented a prepared statement, entitled "Status of Tehachapi Crossing Planning - State Water Project", a copy of which is attached. During this presentation, Mr. Golze' projected slides showing various pumping installations in Europe. A few questions were asked in explanation of the slides, but nothing of a controversial nature was raised.

After the slides were shown, Mr. Wilkes was asked to describe the routes which were studied and presented to the Tehachapi Crossing Consulting Board at that Board's last meeting. At the completion of this presentation, Mr. Golze' completed the reading of his report and opened the meeting to a general discussion.

Following is a brief summary of the various matters discussed by members of the Engineering Committee of the Board of Directors of Metropolitan Water District:

Mr. Robert B. Diemer

Mr. Diemer noted that the Ridge Alignment for the aqueduct seemed to be on competent rock and, therefore the District and the Department of Water Resources should settle on an aqueduct system along this alignment. He was a little apprehensive because the Board of Directors did not have time to review the report of the Tehachapi Crossing Consulting Board prior to this meeting. He felt that proper notification had not been given to the Engineering Committee.

Mr. Skinner informed Mr. Diemer that he personally had notified the Board of Directors prior to the April meeting of the Engineering Committee.

Mr. Diemer indicated that there was no question in the minds of the Directors with regard to Pastoria Canyon because of the poor geologic conditions, but that they were concerned about the multistage pumps proposed for the Ridge Alignment. He stated that the Board of Directors was unsure of the experience record of the European pumping installations which utilized multistage pumps. Mr. Diemer also indicated that en route storage should be investigated on the Ridge Alignment.

At this point, Mr. Diemer challenged the recommendations of the Tehachapi Crossing Consulting Board. However, Mr. Golze' quickly defended the consultants by citing their vast experience and worldwide reputations and integrity.

Mr. Diemer then stated that he felt a three-lift system could be built on the Ridge Alignment, and wondered why the State was gambling on untried multistage pumps as were envisioned for the single-lift system. He also stated that he felt the State should have prepared an estimate of cost for a three-lift system on the Ridge Alignment.

Mr. William S. Peterson

Mr. Peterson questioned the statements of the Tehachapi Crossing Consulting Board with regard to slides being projected into the reservoirs. He stated that with proper drainage and control this could be eliminated.

Mr. Warren W. Butler

Mr. Butler questioned the amount of experience that had been accumulated for operation and maintenance of high head pumps of the multistage variety. Mr. Miller of Daniel, Mann, Johnson and Mendenhall informed Mr. Butler that a considerable amount of experience had been accumulated and that it was covered in their report. Mr. Butler noted, however, that the plants Metropolitan Water District representatives had seen in Europe were all of the pumped storage variety and none had been used for a domestic water system, and that this operation and maintenance experience record was not really commensurate with the contemplated use of the Tehachapi Pumping Plant installation.

Mr. Diemer noted that the pumps to be used for the Tehachapi Pumping Plant would be operated continuously; therefore, since the Tehachapi Crossing Consulting Board concluded that all systems were essentially the same in cost, the Board's decision on a single-lift system must have been made on factors other than cost and operation.

Mr. Golze' answered that the Board considered reliability and dependability as main factors in formulating its conclusions.

Mr. William S. Peterson

Mr. Peterson inquired as to the value of the data that had been accumulated for four-stage and five-stage pump installations. He asked whether there was any evidence of cavitation that would indicate the selection of one over the other, or that one type of pump would run longer than the other. Mr. Miller explained that four- and five-stage pumps do require more operation and maintenance and that this factor was included in Daniel, Mann, Johnson, and Mendenhall's analysis of reliability.

Mr. Miller then explained the method by which reliability was established in DMJM's report.

Mr. R. A. Skinner

Mr. Skinner remarked that European experience on pumped storage projects covered the range of capacities and heads as envisioned for the Tehachapi lift insofar as the use of two-stage double flow pumps are concerned. On the other hand, there are only five European plants which have comparable capacities and heads using four-stage pumps. Mr. Skinner felt that there were two approaches to the problem: (1) environmental in which it is Metropolitan Water District's opinion that the Ridge Alignment is acceptable, and (2) the pump system to be used in which Metropolitan Water District feels that the four-stage pumps are the least reliable of all those considered and that a two-lift scheme utilizing two-stage double flow pumps would be an acceptable system on the Ridge Alignment. Mr. Skinner felt it would be the recommendation of the Metropolitan Water District that the use of a single-lift pumping system be eliminated.

Mr. E. W. Rockwell

Mr. Rockwell reaffirmed Mr. Skinner's statement, stating that in his opinion the four-stage pumps are not good and that the simplest pumping system should be used for the Tehachapi lift. In his estimation, a three-lift system could be made to work satisfactorily.

Mr. Albert F. Bush

Mr. Bush made reference to the Tehachapi Crossing Consulting Board's report and raised the question of the Department of Water Resources' right to make a decision as to what lift would be used on the Tehachapi Crossing without first securing Metropolitan Water District's approval.

Mr. Golze' indicated that the report he had cited was that of the staff of the Department of Water Resources, and that he had not made a final decision as to the lift system for the Tehachapi Crossing.

Mr. Rockwell noted that in the Bechtel report for the Tehachapi lift system, balancing tanks were used for en route storage and that he felt such a system could still be utilized.

Mr. Diemer agreed with Mr. Rockwell in this respect.

Mr. Joseph Jensen

Mr. Jensen felt that the Tehachapi Crossing Consulting Board had not properly considered, nor examined, the efficiencies of the various pumping systems that were cited in the Department of Water Resources' staff report, and that the wishes of the Metropolitan Water District should be given some consideration in the final selection of a pumping system to be used for the Tehachapi Crossing. He agreed that the Ridge Alignment is the best alignment for the system, but argued that it should be a multilift rather than a single-lift system. He stated that single-stage pumps can be made in the United States and that they are reliable. He felt that the four-stage pumps had not been used before in similar situations and Metropolitan Water District considers them to be hazardous. Mr. Jensen also stated that the Department of Water Resources has an obligation to consider MWD's request that the report of the Tehachapi Crossing Consulting Board not be accepted.

Mr. Golze' explained that the Department of Water Resources' reports were based on sound engineering, research, studies, and background, and he would have to have a comparable report from the Metropolitan Water District based on the same type of an investigation before he could be prevailed upon to reject the reports by his staff as well as the report of the Tehachapi Crossing Consulting Board.

Mr. Robert B. Diemer

Mr. Diemer cited the contract that exists between the Department of Water Resources and the Metropolitan Water District, and noted that MWD has a right to make recommendations with regard to the Department's plans and proposals.

Mr. W. C. Farquhar

Mr. Farquhar noted that the Metropolitan Water District is paying over 80 percent and "does not like what MWD is getting".

Mr. Warren W. Butler

Mr. Butler referred back to the efficiencies for the pump units as detailed by Daniel, Mann, Johnson and Mendenhall. He felt that the Tehachapi Crossing Consulting Board did not consider this item in making its recommendation.

Mr. Miller of Daniel, Mann, Johnson and Mendenhall explained how the efficiencies were obtained for the pumps and motors, and how these were used in the preparation of the Department of Water Resources' staff report.

Mr. Butler felt that the Metropolitan Water District could have little confidence in the results of the studies.

Mr. R. A. Skinner

Mr. Skinner raised the question of seismic danger. He believes that the configuration of the four-stage pumps is such that they are more seismic-prone than any other type of installation.

Mr. A. R. Golze'

Mr. Golze' explained to those present that he would have to have a formal statement from Metropolitan Water District's Engineering Committee before he could make a final decision as to the type of system to be used for the Tehachapi pumping lift.

Mr. Butler wanted to know how much time MWD could have to prepare a report. Mr. Golze' asked how much time they wanted, and Mr. Butler indicated that MWD could have a report by the second Tuesday in July, or July 13, and Mr. Golze' agreed to wait for that report.

An additional item which was mentioned during the meeting and reiterated during the closing moments was that the Department of Water Resources should study a three-lift system on the Ridge Alignment and compare it with those systems reported upon in the latest Department report.

The meeting adjourned at 12:30 p.m.

STATUS OF TEHACHAPI CROSSING PLANNING
STATE WATER PROJECT*

By
Alfred R. Golze', Chief Engineer
Department of Water Resources
The Resources Agency
State of California

For fifteen years engineers of the Department of Water Resources have been studying the economic and engineering feasibility of various aqueduct alignments for transporting Northern California water into Southern California. With the publication of Bulletin No. 78 in December 1959 the aqueduct alignment was finalized to go down the west side of the San Joaquin Valley and over the Tehachapi Mountains east of Grapevine (Highway 99). A pump lift of about 2,000 feet was included in the plans to reach the proper crossing elevation (about 3100 feet above sea level). Bulletin No. 78 was reviewed by and received the approval of the consulting engineering firm of Charles T. Main of Boston, Massachusetts. The consultants stated: "We wish to express strongly our opinion that in the future, prior to final design, complete studies and comparisons must be made of all reasonable schemes of pumping and power recovery."

The Burns-Porter Act, named after Senator Hugh Burns and Assemblyman Carley V. Porter, its sponsors, passed the State Legislature and was approved by Governor Brown in 1959 authorizing the State Water Project. With reference to the Tehachapi Crossing it provides (in Section 11260 of the State Water Code): "The units set forth in publication of the State Water Resources Board .. dated May 1951 ... as further modified by the recommendations

*Presented before the Engineering Committee of the Board of Directors of the Metropolitan Water District of Southern California, Los Angeles, California, May 20, 1965.

contained in Bulletin No. 78 of the Department of Water Resources ... and such units and portions thereof, may be constructed by the Department ...."

Following a ratifying vote of the people of the State in 1960, endorsing bond financing of the new State Water Project, detailed engineering and economic studies of the Tehachapi Crossing were undertaken by the Southern District of the Department of Water Resources. As these studies progressed it became apparent that there were two possible alignments at the Tehachapi on the east of Grapevine route and three possible lift arrangements; a single lift of 2,000 feet; a two-lift scheme of 1,000 feet each; and a three-lift scheme of about 670 feet each. In February of this year a finding was approved by me that the three-lift scheme was not practical due to poor geologic conditions at the proposed plant sites. The two alignments continued under detailed study were for (1) a system of works up Pastoria Canyon, and (2) up a rocky ridge called the Ridge Route about a mile east of Pastoria Canyon. Six schemes were given final consideration - 3 two-lift schemes, 3 single-lift schemes with 3 in Pastoria Canyon and 3 on the Ridge Route.

In April 1965 the engineers of the Department completed and submitted to me their report of the investigation of the six schemes. In this report the DWR staff recommends:

> "Proceed immediately with design of a system along the Ridge Route (system 4, Ridge Two-Lift, System 5 Ridge Single-Lift with underground penstocks, or System 6, Ridge Single-Lift with surface penstocks)."

A companion report also dated April 1965 and dealing with the Department's model test program on pumps for the Tehachapi was submitted to me by our consultants, Daniel, Mann, Johnson and Mendenhall. This report found: "Regardless of the pump type selected ... there is not doubt whatever that the pump industry will be able to design and build pumps for Tehachapi that will be reliable and will give satisfactory service over the next 50 years."

My trip to Europe early in April permitted me to discuss high head pump design with European engineers and to visit plants with multi-stage pumps operating under heads exceeding 3,000 feet (Lunersee, Austria). I concur in the statement of our consultants, DMJM.

Early in April the Department's distinguished Consulting Board for Earthquake Analysis was convened to review the seismic situation for the pumping plant schemes proposed at Pastoria Canyon and the Ridge Route. In its report of April 8, 1965 it stated:

> "While the crossing can be effected by either scheme the Ridge scheme is preferable to the Canyon scheme in that it is less vulnerable to damage and presents less potential hazard to life and property.
>
> "Furthermore, in connection with the Ridge scheme, we prefer the use of tunnels in sound rock to surface installations in weathered material on steep slopes."

On May 3 the Department's eminent Tehachapi Crossing Consulting Board assembled in Bakersfield for a field trip over the Pastoria Creek Canyon and Ridge Route alignment and plant sites. The balance of the week was spent by the Board in Sacramento. On May 5 the Betchel Corporation, as consultants for the Metropolitan Water District of Southern California, presented to the Crossing Board their findings: (1) on the lift concept and (2) of the pump studies being made at East Kilbride, Soctland. Betchel accepted the Pastoria Canyon Route as infeasible geologically and recommended a two-lift pump system on the Ridge Route. It further recommended that pump selection be deferred pending further model testing of single-stage pumps for a 1,000 foot head. Robert Skinner, Chief Engineer and General Manager speaking for MWD, generally supported the Betchel findings with the added statement that he considered the single-lift concept to be the least optimum of the several choices available.

The comments of Professor Hans Gerber, Swiss Federal Institute of Technology, Zurick Switzerland, Consultant to Bechtel, as presented to the Board, are worth noting:

> "We think that the choice of a single-lift, a two-lift or three-lift solution is first of all a topographical, geological and seismic problem. It should clearly be stated that, independent of costs, it would be possible for all three lift solutions to have reliable and rugged pumps built and for all these pumps long years of experience of different kinds are available."

Department staff and DMJM made separate presentations to the Board on May 6. The DWR presentations showed that the Ridge Route was the most feasible one. For the lift scheme it was clear to DWR staff that either the single-lift or two-lift scheme could be built but there were important factors to be considered for each lift. These factors were presented in detail by DWR staff and DMJM. Representatives of MWD were present during these presentations to the Board.

The Crossing Board considered these factors at length. It has submitted a report to me under date of May 8, a copy of which is attached. It recommends the Ridge Route single-lift scheme with underground discharge pipes. The reasons supporting this recommendation are set forth in its report. They can be summarized by stating the Board found the Ridge Route superior from the geology and seismic hazard viewpoint, recommending the single-lift scheme as the safest and most reliable of the two schemes possible on the Ridge Route, having roughly half the hazard exposure and mechanical complexity of the two-lift scheme.

Consideration has been given by DWR staff to the report and recommendations of the Tehachapi Crossing Board. The three major suppliers of the American pump industry have assured us they can build and will bid on plans for multi-stage pumps for the single lift. DWR staff therefor accepts the recommendations of the Board for a single lift on the Ridge Route, but feels the question of whether the penstocks should be underground or surface needs more study.

Mr. Alfred R. Golze',
Chief Engineer
Department of Water Resources
P.O. Box 388
Sacramento 2, California

July 9, 1965

Subject: Tehachapi Pumping Facility
DMJM Job No. 637-1-1
"Considerations Relating to a Single Lift for the Tehachapi Crossing"

Dear Mr. Golze':

In response to your request, the Daniel, Mann, Johnson, & Mendenhall Technical Advisory Board was in session at the DMJM offices in Los Angeles on July 7, 8 and 9, 1965, for the purpose of reviewing certain specific considerations relating to the single lift concept for the Tehachapi Crossing.

Present at the meeting were:

Irvan F. Mendenhall	- Chairman
John T. Clabby	- Member
Leslie J. Hooper	- Member
Austin H. Church	- Member
Otto Hartmann	- Acting for Peter Jaray
David R. Miller	- Secretary
John Parmakian	- Liaison Representative from the Tehachapi Crossing Consulting Board

The Board sessions were as follows:

July 7, 1965 - Review of DMJM report entitled "Considerations Relating to a Single Lift for the Tehachapi Crossing". General background briefing on techincal aspects of the multi-stage pumps, interface equipment and penstocks for the single-lift concept.

July 8, 1965 - Presentations to the Board by:

- Allis-Chalmers/Sulzer
- Baldwin-Lima-Hamilton/Voith
- Newport News/Escher-Wyss
- DMJM Staff presentation on Design Parameters and Model Test Program
- Motor-Columbus presentation on European Practice in Multi-stage Pumps and Penstocks

July 9, 1965 - (morning) DMJM Staff presentation on Reliability

In the afternoon of July 9, the third meeting of the Technical Advisory Board convened in closed session and reached various conclusions as follows:

I Previous reports and studies have found the single-lift system to be the best choice for the Tehachapi Crossing because of its simplicity and overall reliability as compared to multi-lift concepts. Based on these studies and our own review and analysis of specialized aspects of the problems, the Technical Advisory Board endorses the choice of the single-lift system.

II Further consideration and continued evaluation of the pumps and interface equipment for the single-lift fully support the foregoing conclusion. Technical Advisory Board determinations include:

A. Pumps:

1. Four-stage Pump - At the onset of this program, the four-stage, single suction centrifugal pump was selected from many studies as most suitable for the Tehachapi single-lift. The research and development program, which has been one of the most comprehensive ever undertaken, along with the

expert opinions of leading authorities and consultants, has fully confirmed that the four-stage machine can be depended upon to give efficient reliable service, and it represents the optimum for the Tehachapi application.

2. Efficiency - The results of the model test program have shown that the four-stage pump meets performance requirements satisfactorily. Based on a measured model efficiency of 88.85%, results to date show that an efficiency of approximately 91% can be expected for the prototype pump, and it may be possible to achieve 92%. One of the important factors contributing to this high efficiency has been the selection of an optimum specific speed. The specific speed previously recommended (N_s = 2160) is hereby confirmed as the best choice for the Tehachapi conditions.

3. Precedent - There exists adequate precedent and previous experience upon which to base the Tehachapi four-stage pump design. The Tehachapi conditions are in effect bracketed by existing installations in Europe. Many of these installations are for pumped-storage purposes and, as such, their intermittent operating conditions are in some respects more severe than would be realized under continuous operation at Tehachapi.

4. Model Testing Results - While the normal practice in the design of models for multi-stage pumps has been to use only two or three stages (at most) for the prediction of performance of four and five-stage pumps, The Tehachapi model has been designed to include all four stages and is considerably larger than usual practice. The model program has indicated design improvements which will result in substantial increases in efficiency over existing units. Furthermore, test results of the two-stage model using established model correlation techniques have validated the indicated efficiency of the four-stage model. The extensive model test program provides a broader than usual basis for the prediction of prototype performance.

5. Reliability - The research and development program has included a most exhaustive study of failure and behavior experience of existing pumping units. This information has been analyzed, using advanced reliability techniques. Based on this information, it is concluded that the four-stage machine will provide a very high degree of reliability with minimum maintenance.

6. Maintenance - A major investigation has been made of existing pumps, particularly regarding the wearing elements such as balancing labyrinths and wearing rings. To this body of knowledge has been added the results of the special wear test program which allows an evaluation of the effect of water quality on the longevity of pump wearing elements. With the anticipated water quality, no excessive maintenance is foreseen.

7. Manufacturers - There is no question as to the ability of U.S. Manufacturers to build the multi-stage machine based on designs which have been proven in European practice. Responsible manufacturers have clearly stated no departure from the present state of the art or technology is involved, and have expressed great confidence in their ability to design and build a highly reliable, efficient and serviceable unit.

B. Motors:

The single-lift concept entails electrical motors of 76,000 HP, running at 600 rpm. Such motors are within the capability of U.S. Manufacturers, however, final determinations regarding starting methods must be made.

C. Valves:

Discharge valve requirements are well within the state of the art.

DMJM

D. Discharge Lines:

A preliminary investigation has been made of the technical problems in high head penstock design. While some special considerations are involved, the single-lift discharge lines are within the range of current practice. It is not considered necessary to resort to high strength quenched and tempered steel for the single-lift discharge line.

We are pleased to transmit herewith the DMJM report entitled "Considerations Relating to a Single Lift for the Tehachapi Crossing". This report was provided each member of the Technical Advisory Board prior to the meeting.

Yours very truly,

DANIEL, MANN, JOHNSON, & MENDENHALL

Irvan Mendenhall

Irvan F. Mendenhall
President
/vi

cc: Addressee (2)
J. T. Clabby
L. J. Hooper
A. H. Church
S. L. Kerr
P. Jaray/O. Hartmann
J. Parmakian

THE RESOURCES AGENCY OF CALIFORNIA

Department of Water Resources

TEHACHAPI PUMPING PLANT

RESEARCH AND DEVELOPMENT PROGRAM

CONSIDERATIONS RELATING to a SINGLE LIFT for the TEHACHAPI CROSSING

July 1965

DANIEL, MANN, JOHNSON, & MENDENHALL
Engineering Division
Los Angeles

Associate Consultants
MOTOR-COLUMBUS
Baden /Switzerland

CONSIDERATIONS RELATING TO A SINGLE LIFT

FOR THE TEHACHAPI CROSSING

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SINGLE LIFT REPORT

1. Introduction:

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   b) Conclusions reached on pump types, based on this study.

   c) Suitability of selected pump for single lift system is object of this report.

2. Precedence and Experience:

   a) Review of applicable (European) installations

   b) Detailed discussion of extrapolation, particularly Lunersee installation to Tehachapi.:

      1. Design and physical size, complexity.
      2. Speed and specific speed.
      3. Head per stage.
      4. Operating conditions.

   c) Statements by U. S. manufacturers pertaining to the selected pump type.

3. Analytical Studies for 4-Stage Machine:

   a) Specific speed analysis.

   b) Submergence requirement analysis.

   c) Critical speed analysis.

   d) Detailed study of 4-stage prototype pump design.

4. <u>Model Test Program:</u>

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   b) Results of model test program - latest efficiency data.

   c) Predicted prototype efficiency from model test data.

5. <u>Wear Test Program:</u>

   a) Resume of results to date.

   b) Preliminary conclusions resulting from test results.

6. <u>Reliability of 4-stage Pump:</u>

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   b) Detailed reliability study of 4-stage pump.

7. <u>Discharge Pipe and Manifold Study:</u>

   a) Experience report on "T-1" Steel

   b) Outline of Proposed DMJM Study.

8. <u>Summary, Conclusions and Recommendations:</u>

TECHNICAL ADVISORY BOARD MEETING

PROPOSED AGENDA

Tuesday, June 29, 1965:

A.M.	Closed Session	- Study Staff Report.
P.M.	Closed Session	- Briefing on Problems & Objectives

Wednesday, June 30, 1965:

0800 - 0900		
0900 - 1000	-	A/C - Sulzer Presentation
1000 - 1030	-	Break and Questions
1030 - 1130	-	BLH-Voith Presentation
1130 - 1200	-	Questions
1200 - 1300	-	Lunch
1300 - 1400	-	Newport News/Escher Wyss Presentation
1400 - 1430	-	Questions and Break
1430 - 1530	-	Staff Presentation - Design Extrapolation
1530 - 1630	-	Staff Presentation - 4-stage Machine Reliability
1630 - 1730	-	Motor-Columbus - European approach.

Thursday, July 1, 1965:

0800 - 1000	-	Discussion by MWD/Bechtel
1000 - 1200	-	DMJM Staff Summary
1200 - 1300	-	Lunch
1300 - 1700	-	Closed Session - Findings, Conclusions and Recommendations.

TAB MEETING PARTICIPANTS

1. Technical Advisory Board:

I. F. Mendenhall	Chairman
J. C. Clabby	Member
Peter Jaray/or Otto Hartmann	"
S. Logan Kerr	"
Leslie J. Hooper	"
Austin H. Church	"
John Parmakian	Liaison Representative from Tehachapi Crossing Board

2. DMJM/Motor-Columbus Staff:

D. R. Miller - Project Director
Hans Gartmann - Project Engineer
R. D. Bowerman - Asst. Proj. Engr. & Hydraulic Engr.
R. A. Hall - Systems Engineer
G. E. Benz - Reliability Engineer
Otto Hartmann - Mechanical Engineer
(Niklaus Schnitter - Civil Engineer)

3. DWR Staff:

Ted W. Troost   A. R. Golze'
Anthony Hunter   D. P. Thayer

4. MWD:
Engineering Committee - Board of Directors
R. A. Skinner and
MWD Staff as designated

5. Bechtel Corporation:

M. L. Dickinson

6. Manufacturers:

(to be designated)

THE METROPOLITAN WATER DISTRICT
OF SOUTHERN CALIFORNIA
1111 SUNSET BOULEVARD
LOS ANGELES, CALIFORNIA

OFFICE OF
GENERAL MANAGER AND CHIEF ENGINEER

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JUL 19 1965

Mr. Alfred R. Golze'
Chief Engineer
Department of Water Resources
P.O. Box 388
Sacramento 2, California

Dear Mr. Golze':

At a special meeting of the Engineering and Operations Committee of the District's Board of Directors on May 20, 1965, you read a statement from the Tehachapi Crossing Consulting Board recommending that the ridge single-lift scheme with underground discharge pipes be adopted for the Tehachapi pump lift. You reported also that the DWR staff accepted the recommendation of the Board for a single-lift on the ridge route, but felt that the question of whether the penstocks should be underground or on the surface needs more study. At the conclusion of your presentation you stressed the point that you had not rendered a decision on the type of lift to be selected and further offered to withhold the decision until after the July meeting of the District's Board of Directors in order to afford the District an opportunity to prepare and present to you a comprehensive report on a pumping system that the District would recommend be built for the Tehachapi Crossing.

The District has prepared a report titled "Recommendation of the Adoption of a Two-Lift System along the Ridge Alinement for the Tehachapi Crossing of the California Aqueduct" dated July 1965, and concurrently Bechtel Corporation has prepared for the District "Report on Ridge Location Pump Systems, Single-Lift and Two-Lift, for the Tehachapi Crossing of the California State Water Project" dated July 1965.

I submitted the aforementioned two reports to the District's Board of Directors with letter dated July 9, 1965, of which a copy is attached, recommending approval and adoption of the reports as presenting the District's position in regard to the selection of the optimum pumping system for the Tehachapi Crossing. This recommendation was approved by the Board's Engineering and Operations Committee at its meeting on July 12 and by the Board at its meeting on July 13, 1965.

The two-lift system recommended in the District's report referred to above would utilize a reservoir at the off-line site near the upper pumping plant for storage and automatic balancing of the flow of water through the two pumping plants. Bechtel in its report strongly supports the adoption of the two-lift system.

Two-stage, double-flow pumps mounted with shafts in the horizontal position and with split casings to facilitate maintenance and repair are recommended for use in the two-lift system. This recommendation is fully supported by Professor Hans Gerber of Zurich, Switzerland, a recognized authority with outstanding experience in the design, installation, and testing of large pumping units in Europe, and a consultant to Bechtel. However, it is recommended that the results of the testing program on models of single-stage and multistage pumps being conducted by Bechtel Corporation at the National Engineering Laboratory in East Kilbride, Scotland, be completed and reviewed before specifications are issued for procurement of pumps.

Underground discharge lines are proposed for the two-lift system. The two consulting Boards retained by your Department to review recommendations pertaining to the Tehachapi Crossing have recommended the use of underground discharge lines for reasons of safety and reliability, and Bechtel concurs in this recommendation.

The supporting arguments for the recommendation that a two-lift system should be adopted as the most reliable, dependable, and efficient pumping system for the Tehachapi Crossing are summarized at the beginning of the District's report. The sources of information indicating the advantages of the various components of a two-lift system are given in the remainder of the report together with the development of arguments supporting the selection of such a system. Extensive use was made of the data contained in the reports on the Tehachapi Crossing prepared by your Department and your consultants as well as the reports prepared by Bechtel Corporation and its consultants.

The Bechtel report mentioned above develops and compares three alternative systems, one single-lift and two with two lifts, along the ridge location at Tehachapi, each having two underground discharge lines. Drawings of the alternative arrangements along the ridge alinement are included in Bechtel's report; however, Bechtel has indicated that these arrangements and details are suggested as having possible merit, but not necessarily as Bechtel's recommendation for final design of the selected system.

I have taken the liberty of including in the District's report comments on general design and surveillance problems which are beyond those pertinent to the issue of selecting a type of pumping system. It is hoped that you may find some of these comments helpful during the detail designing of the system selected.

Your attention is called in particular to the recommendation that two valves be used in series on the discharge side of each pump. The use of an extra valve for pump discharge service has been suggested tentatively in previous DWR reports. The importance of this precaution was accentuated by the recent failure of a discharge valve in one of the District's pumping plants to close completely under emergency tripping of the unit off of the line. A shaft bearing in the valve had worn to such an extent that the resulting displacement of the plug prevented normal operation of the valve. In order to replace the bearing, the other pumps connected to the discharge line with the defective discharge valve will have to be taken out of service while the line is dewatered to permit repairs. At Tehachapi it is proposed to use only two discharge lines. If it would become necessary to dewater one of the two lines to repair a discharge valve, one-half of the units would be taken out of service. With two discharge valves in series, the downstream valve could be closed to enable the operating valve to be taken out of service for repair. The downstream valve would be reserved for use as a shut-off valve in such emergencies, and would not be subjected to the hard usage imposed on the operating valve.

On July 8 and 9, 1965, the Technical Advisory Board of your research and development consultant Daniel, Mann, Johnson, and Mendenhall met in Los Angeles to hear presentations by DMJM and by three manufacturers of multistage pumps principally relating to application of a four-stage pump for a single-lift system at Tehachapi, and to the suitability of such a pump for such application. Representatives of the District were invited and attended the meeting. The information presented during the meeting has not been specifically discussed in either the District's report or Bechtel's report, both of which were substantially completed and in process of review prior to the meeting. However, it was not found necessary by either the District or Bechtel to alter the conclusions or the recommendations set forth in their respective reports, after studying the additional information disclosed at the DMJM meeting, and reviewing the ensuing report of the Technical Advisory Board dated July 9, 1965.

It is requested that you give careful consideration to the recommendations contained in the two reports transmitted herewith, which have been approved and adopted by the Board of Directors as representing the District's position in regard to the selection of the optimum system for the Tehachapi Crossing. This recommendation is made after considering all of the evidence which has been collected and made available to the District in the research and development program being conducted both by the Department and its consultants and Bechtel Corporation and its consultants. The District is firmly convinced that a two-lift system should be adopted for the Tehachapi Crossing.

Very truly yours,

R A Skinner

R. A. Skinner
General Manager and Chief Engineer

Encl. 9090

July 9, 1965

Board of Directors
The Metropolitan Water District
of Southern California
B u i l d i n g

Gentlemen:

In accordance with the understanding reached by the Engineering and Operations Committee at its meeting on May 26, 1965, a comprehensive report has been prepared recommending the adoption of a two-lift pumping system along the ridge alinement for the Tehachapi Crossing of the California Aqueduct.

The two-lift system would utilize a reservoir at the off-line site near the upper pumping plant for storage and automatic balancing of the flow of water through the two pumping plants. Bechtel has concluded in the studies made on the Tehachapi Crossing that the two-lift system is the most favorable system and should be adopted.

Two-stage, double-flow pumps mounted with shafts in the horizontal position and with split casings to facilitate maintenance and repair are recommended for use in the two-lift system. This recommendation is fully supported by Professor Hans Gerber of Zurich, Switzerland, a consultant to Bechtel. It is recommended in the report that the results of the pump model testing program being conducted by Bechtel Corporation at the National Engineering Laboratory in East Kilbride, Scotland, should be reviewed before specifications are issued for procurement of pumps.

Underground discharge lines are proposed for the two-lift system. Two consulting Boards retained by the Department of Water Resources have recommended the use of underground discharge lines for reasons of safety and reliability, and Bechtel concurs in this recommendation.

The recommendation that a two-lift system should be adopted as the most reliable, dependable, and efficient pumping system for the Tehachapi Crossing and the supporting arguments are summarized at the beginning of the report. The sources of information giving the advantages of the various components of a two-lift system are given in the remainder of the report together with the development of the arguments supporting the selection of such a system. Extensive use was made of the data and information contained in the reports on the Tehachapi Crossing prepared by the Department of Water Resources and its consultants and by Bechtel Corporation and its consultants.

Bechtel Corporation has submitted a report on Ridge Location Pump Systems for the Tehachapi Crossing, recommending adoption of a two-lift system. Drawings showing alternative arrangements of the proposed two-lift system are included in this Bechtel report.

A copy of the report prepared in this office recommending the adoption of a two-lift system for Tehachapi and a copy of the aforementioned Bechtel report are transmitted herewith.

It is recommended that the two reports be approved and adopted as presenting the District's position in regard to selection of the optimum system for the Tehachapi Crossing, and that they be transmitted to the Department of Water Resources with a statement urging the Department to adopt a two-lift pumping system for construction at the Tehachapi Crossing.

Very truly yours,

R. A. Skinner
General Manager and Chief Engineer

Enclosure

THE METROPOLITAN WATER DISTRICT
OF SOUTHERN CALIFORNIA

RECOMMENDATION OF THE ADOPTION OF A TWO-LIFT SYSTEM ALONG THE RIDGE ALINEMENT FOR THE TEHACHAPI CROSSING OF THE CALIFORNIA AQUEDUCT

- - -

JULY 1965

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Recommendation of the adoption
of a two-lift system
along the Ridge Alinement
for the
Tehachapi Crossing of the California Aqueduct

SUMMARY

A substantial amount of data has been assembled on alternative costs, geology, seismic hazards, pump characteristics, motor problems, steel for discharge lines, auxiliary equipment, operating experience on existing pumping plants, and reliability factors to compare alternative concepts of pumping systems for the Tehachapi Crossing of the California Aqueduct. These data are contained in reports prepared by the Department of Water Resources, consultants to the Department, Bechtel Corporation, and consultants to Bechtel.

All of these reports have been reviewed and the data evaluated to determine a pumping system which is adaptable to the environmental factors of topography, geology, stream flow, and streambed debris transport, among others, which will be the most reliable, dependable, and efficient and which can be constructed at a reasonable cost when compared with the alternative systems.

In a letter dated March 12, 1965, the Metropolitan Water District recommended that the Department of Water Resources decide upon a three-lift system in Pastoria Creek for the preparation of

final plans and in addition start preparation of final plans for a two-lift system as an alternative so that in the event the testing program establishes that a single-stage pump is suitable for a two-lift system, a change in the type of system can be made without loss of time insofar as scheduling of construction is considered.

Subsequently, Department geologists and Bechtel geologists have explored Pastoria Canyon in more detail and have found it inadvisable to use the canyon for the route of the proposed Tehachapi Crossing pumping system, thus eliminating the possibility of adopting a three-lift system.

Furthermore, the testing program being conducted by Bechtel has not progressed to the point where a determination can be made as to the suitability of the single-stage pump for the two-lift system.

It has been concluded after reconsidering all of the aforementioned data which have been assembled, that a two-lift system on the ridge alinement utilizing underground discharge lines, an off-line reservoir, and two-stage, double-flow pumps is the optimum system and should be constructed at the Tehachapi Crossing. The pumps should be of a size that will permit delivery of the full conveyance capacity of the California Aqueduct at Tehachapi with seven pumps. An eighth pump should be installed as a spare unit to permit a regular program of routine maintenance and overhaul on one unit at a time leaving seven units for pumping the full flow of water in the aqueduct at the Tehachapi Crossing. The pumps should have split cases and should be installed with the shafts in a horizontal position at an elevation that will provide adequate submergence as determined by tests on model pumps to prevent cavitation at low water level in the forebay or reservoir.

The following advantages support the selection of a two-lift system using two-stage, double-flow pumps installed with the shafts in a horizontal position:

1. The geology of the upper plant and reservoir is more favorable than that for the lower plant and forebay. While it is not possible to eliminate the use of the lower site for any system along the ridge alinement, it is possible to reduce the number of pumping units at the lower plant by using the two-lift system.

2. It has been stated that hazards due to seismic acceleration are increased with the number of structures. Each pumping unit should be considered as a structure. There would be 16 units in a two-lift system as compared with 14 units in a single-lift system, including spare units. There is very little difference in the number of pumping units; however, one-half of the units in a two-lift system would be located on good rock as compared to locating all of the pumps for a single-lift system on the Tejon sandstone formation which exists at the bottom of the lift.

3. Damage from seismic accelerations would be less on a two-stage, double-flow pump mounted with the shaft in a horizontal position than on a four-stage pump with the shaft mounted in a vertical position and supported at the motor base, at the top of the pump by bolted connections, and at the base of the pump on a pedestal.

4. Underground discharge lines afford the greatest safety and reliability. With a two-lift system steel plate of an intermediate grade and with a thickness not exceeding 2 inches can be used which is within the limits established by favorable experience in penstock fabrication.

5. A two-stage, double-flow pump is the most efficient multistage pump and has been developed for more pumped storage plants than any other type of multistage pump. Tests on DWR models show an efficiency for the two-stage pump model 2-1/2 percent higher than that for the four-stage, single-flow pump. The results of field tests on existing installations show substantially higher efficiency for the two-stage, double-flow pump than for the four-stage, single-flow pump.

6. The construction, arrangement, and location of a two-stage, double-flow pump facilitates maintenance and repair if set with shaft in horizontal position.

7. Two-stage, double-flow pumps with shafts in a horizontal position are started in some plants with casings dewatered in order to reduce the starting load. There is no precedent in existing installations for starting pumps of three or more stages with cases dewatered.

8. A two-stage, double-flow pump installed with the shaft in a horizontal position does not require a thrust bearing because hydraulic thrusts are balanced within the pump.

9. A two-stage, double-flow pump is the most favorable type of pump for operation without excessive wear, maintenance, and loss of efficiency when pumping water containing abrasive materials.

10. Pump discharge valves for a two-lift system will be required to withstand pressures only half of that in a single-lift system. Two discharge valves in series are recommended to permit repair of the valve normally used for shutoff without interfering with the operation of the other pumping units.

11. Since there is a total of 16 units in the two-lift system and 14 units in a single-lift system counting a spare, there are only two more sets of pump controls required on a two-lift system. In addition, there are only two more sets of water level control devices required for the off-line reservoir.

With careful control of design, procurement and installation of the control equipment, the two additional sets of controls will not decrease the reliability if a proper maintenance program is scheduled.

12. The two-lift system can be made self-balancing in regard to the amount of water pumped at each plant.

13. The cost of a two-lift system is considered equal to that of a single-lift system within the accuracy of the estimates.

14. Dependability and reliability must be built into a system by selecting appropriate design criteria, by the rigorous analysis and application of engineering principles in designing the system and each component, in the preparation of detailed specifications for equipment based on the results of surveys of existing installations, and thorough inspection to control the quality of each component during fabrication and of the pumping system as a whole during construction.
A two-lift system utilizes components which have the most extensive record as far as operation is concerned and which will permit the construction of the most reliable and dependable system without using equipment, materials, and methods not fully developed to date.

Professor Hans Gerber of Zurich, Switzerland, supports a two-lift system in his letter of June 9, 1965, to Bechtel Corporation for which he is acting as a consultant. His statement sums up the two-lift system as follows:

> "Dealing with a 2-lift solution there remains the question of type of pump. Perhaps in some years when operating performance of some pumping plants is available (from Robiei, Ronckhausen, Cruachan and others) I would simply claim for the vertical shaft single-stage single-suction pump."
>
> "But these experiences are not present, and we are not allowed to work with them as fully valuable proofs. Therefore, with a maximum of long years operating data and experiences, the horizontal (or even vertical!) shaft double-stage double-suction pump type proves to be by far the best solution. All the advantages are well known, and it seems unnecessary to repeat them. May I remind only that for this type of pump experiences are available over more than 30 years from more than 30 pumping plants with almost 70 units, built by the four European Manufacturers and including all characteristics of the future Tehachapi pumps. This will enable those in duty to work out very clear and consistant specifications to make sure that the tenders coming in are all on the same base and of the highest possible technical level."

I. INTRODUCTION

A. <u>Contract provisions permitting District to review and comment on plans of the Department of Water Resources</u>

Under Section 17(c) of the contract between the State of California Department of Water Resources and The Metropolitan Water District of Southern California for a water supply, dated November 4, 1960, it is stated that "The District shall have a reasonable opportunity to inspect and study the State's plans and specifications for all project facilities during the planning stage and prior to the solicitation of bids for the construction thereof, and may make comments and recommendations thereon to the State."

Because of the initial importance to Southern California of the pumping system at the Tehachapi Crossing of the California State Water Project both in respect to dependability, initial cost, and operation and maintenance costs, the District has undertaken a comprehensive study of high-lift multistage pumps of the type being considered by engineers of the Department of Water Resources, State of California, for the proposed Tehachapi pumping plant of the State water project and of alternative systems which might be used.

B. Offer to make joint study with Department of Water Resources

In a letter dated September 20, 1963, to Mr. William E. Warne, Director of Water Resources, the District reported that the Board of Directors had authorized negotiations with the Department to determine whether such arrangements could be made for a jointly sponsored investigation to be performed by Bechtel Corporation or other consulting engineering firm with preeminent qualifications in hydro and related fields.

In the aforementioned letter to Mr. Warne, it was stated that "It would be understood that the District would bear half the expense of the investigation and would participate jointly with the Department in establishing the guide lines for the study."

It was further stated that "The Board . . . authorized negotiation of a contract with Bechtel Corporation to make the investigation on behalf of the District in the event that the Department does not wish to enter into a joint arrangement with the District for the study."

C. Memorandum of Understanding

The Department declined to accept the District's proposal of jointly sponsoring an investigation by a consulting firm but offered the District an opportunity to participate in an expanded research and development contract and in comparative studies to be made by the

Department. The District accepted the offer to participate but pointed out that the District expected to engage consultants to assist and advise the District in evaluating the comparative studies.

A Memorandum of Understanding was signed by the District on January 28, 1964, and by the Department of Water Resources on March 10, 1964, setting forth the guidelines under which the District could participate in the research and development program and the Department's studies.

D. Agreement with Bechtel Corporation to make authoritative study

Under an agreement dated February 26, 1964, Bechtel Corporation has reviewed for the District the work performed by the State and its research and development consultants, pertaining to the selection of pumping equipment and other facilities for the Tehachapi Crossing of the California State Aqueduct and has conducted an independent comparative study of single-lift and multilift pumping equipment and systems for the crossing in cooperation with Metropolitan engineers.

E. Model tests at National Engineering Laboratory

Bechtel Corporation negotiated a contract with the National Engineering Laboratory, at East Kilbride, Glasgow, Scotland, to test model pumps obtained from various American and European manufacturers for the purpose of obtaining information necessary for the selection of the most suitable pump for Tehachapi Crossing. The laboratory is an entity of the British Government, is fully equipped to perform the required tests, and has no connection with manufacturers.

F. Reports by the Department of Water Resources

The Department of Water Resources has prepared the following reports, among others, on the results of its studies for the Tehachapi pumping plant of the California Aqueduct:

Preliminary Report of Technical and Economic Feasibility of Single Lift, Two Lift And Three Lift Systems; Tehachapi Pumping Plant, September 1964

Report on Alternative Locations of Tehachapi Lift System, April 1965

G. Reports by the Consulting Board for Earthquake Analysis

The Department of Water Resources has retained eminent consultants to serve on a Consulting Board for Earthquake Analysis. Among the reports which have been submitted to the Department are the following pertaining to the Tehachapi Crossing:

Letter of May 27, 1964, to Alfred R. Golze', Chief Engineer of the Department of Water Resources

Memorandum of December 22, 1964, on seismic hazards concerning Tehachapi Crossing

Letter dated April 8, 1965, to
Mr. Alfred R. Golze'

H. Reports by Daniel, Mann, Johnson, and Mendenhall

A research and development contract was awarded the engineering firm of Daniel, Mann, Johnson, and Mendenhall by the Department of Water Resources. The contract stipulated that the engineering firm conduct a model pump testing program wherein pump manufacturers would build and test models of pumps being considered for Tehachapi. Three models were built for testing; a single-stage model for a three-lift system, a two-stage, double-flow model for a two-lift system, and a four-stage model for a single-lift system. The contract also permitted studying operation and maintenance data on existing pump installations, motor performance characteristics, valve designs and related problems.

The following reports have been prepared by DMJM:

Tehachapi Pumping Facility,
California State Water Project,
Research and Development Program,
Monthly Progress Reports No. 1-21

Efficiency - Specific Speed
Relationships

Wear Test Program
Summary and Progress

Status of Byron Jackson
PERT Control

Status of Baldwin-Lima-Hamilton/Voith
PERT Control

Model Test Firm Semi-monthly
PERT Reporting Procedure

Interim Report, Investigation of High
Head Pumping Practice In Europe,
October 1964

Tehachapi Pumping Plant,
Comparative Analysis of Lift Concepts
Pumps and Interface Elements,
April 1965, 4 Volumes

Considerations Relating to a Single
Lift for the Tehachapi Crossing,
July 1965

I. Reports by Bechtel Corporation and its consultants

Bechtel Corporation and its consultants have presented interim reports on alternative pumping systems, survey of pumping equipment in existing European and American plants, pump tests being conducted at National Engineering Laboratory, and metallurgical factors having a bearing on penstock construction. The conclusions expressed in the following Bechtel interim reports are subject to possible change on the basis of analysis of additional data to be obtained in the research and development program being continued at the National Engineering Laboratory:

Report on Alternative Schemes for the Tehachapi Crossing of the California State Water Project, Bechtel Corporation, September 1964

Metallurgical Report on Steels for Discharge Pipes for the Tehachapi Crossing of the California State Water Project, Bechtel Corporation, October 1964

Interim Report on European Pump Practice In Connection with Studies for the Tehachapi Crossing of the California State Water Project, prepared by Professor Hans Gerber, Consultant and Dr. Robert A. Sutherland, Consultant Bechtel Corporation, October 1964

Interim Report on Bechtel Studies of Tehachapi Pump Lift, presented to California Department of Water Resources and the Tehachapi Crossing Consulting Board by M. L. Dickinson, Chief Hydraulic Engineer, Bechtel Corporation, October 22, 1964

Interim Report on American Practice In Large Capacity High Head Centrifugal Pumps in Connection with Studies for the Tehachapi Crossing of the California State Water Project, prepared by Ray S. Quick, Consultant, Bechtel Corporation, October 1964

Remarks by Professor Hans Gerber at Meeting of the Tehachapi Crossing Consulting Board at Sacramento, California, Bechtel Corporation, October 22, 1964

Second Interim Report on Alternative Schemes for the Tehachapi Crossing of the California State Water Project, Bechtel Corporation, January 1965

Progress Report No. 2 on Pump Test Programme for the Tehachapi Crossing of The California State Water Project, prepared by Fluid Mechanics Division, National Engineering Laboratory, East Kilbride, Scotland, Bechtel Corporation, January 1965

Report on Survey of American Practice in Large Capacity High Head Centrifugal Pumps And Pump Turbines, prepared by Ray S. Quick, Consultant, Bechtel Corporation, January 1965

Second Report on European Pump Practice, prepared by Professor Hans Gerber, Consultant, and Dr. Robert A. Sutherland, Consultant, Bechtel Corporation, January 1965

Progress Report on the Evaluation of Geologic Conditions for Alternative Schemes on the Tehachapi Crossing Project, Bechtel Corporation, April 1965

Model Pump Test Program, National Engineering Laboratory, East Kilbride, Scotland, Professor Lawrence C. Neale, Consultant, Bechtel Corporation, April 1965

Geologic Progress Report No. 2 on Alternative Schemes for the Tehachapi Crossing, Bechtel Corporation, April 30, 1965

Summary on Report on Survey of American Practice in Large Capacity High Head Centrifugal Pumps and Pump-Turbines, prepared by Ray S. Quick, Consultant, Bechtel Corporation, May 1965

Tehachapi Pump Lift System, General Remarks by Julian Hinds, Consultant, Bechtel Corporation, May 1965

Tehachapi Pump Lift, Comments on Recommendations of State DWR, presented to Engineering and Operations Committee of MWD by M. L. Dickinson, Chief Hydraulic Engineer, Bechtel Corporation, May 26, 1965

Discussion of Alternative Schemes for the Tehachapi Crossing of the California State Water Project, Bechtel Corporation, May 5, 1965

Tehachapi Pump Lift, Comments on Recommendations of Tehachapi Crossing Consulting Board in Letter of May 8, 1965, to Department of Water Resources on Preferable Selection of Type of Pump and Lift Arrangement, Ray S. Quick, Consultant, Bechtel Corporation, May 1965

Tehachapi Pump Lift System, Comments on Use of Model Data, Professor Lawrence C. Neale, Consultant, Bechtel Corporation, May 1965

Tehachapi Pump Lift System, Additional Remarks on European Pumping Practices, Professor Hans Gerber, Consultant, Bechtel Corporation, May 1965

Bechtel Studies of Tehachapi Pump Lift, M. L. Dickinson, Chief Hydraulic Engineer, Bechtel Corporation, May 5, 1965

Telegram of February 25, 1965, from Professor Hans Gerber, Consultant, regarding European pump manufacturers' willingness to bid on Tehachapi pumps

Telegram of February 24, 1965, from Allis-Chalmers Manufacturing Company regarding its interest to bid on Tehachapi pumps

Telegram of May 24, 1965, from Baldwin-Lima-Hamilton regarding its interest to bid on Tehachapi pumps

Telegram of May 24, 1965, from Byron Jackson Pumps, Inc., regarding its interest to bid only on single-stage pumps for Tehachapi

Telegram of May 25, 1965, from Newport News Shipbuilding and Drydock Company regarding its interest to bid on pumps for Tehachapi

Telegram of May 24, 1965, from Sulzer Brothers, Ltd., regarding its interest to bid on Tehachapi pumps

Telegram of May 25, 1965, from J. M. Voith Company regarding its interest to bid on Tehachapi pumps

Letter of May 22, 1965, from Julian Hinds, Consulting Engineer, to M. L. Dickinson, Chief Hydraulic Engineer, Bechtel Corporation, regarding the May 8 report of the Tehachapi Crossing Consulting Board

Report on Ridge Location Pump Systems Single-Lift and Two-Lift for the Tehachapi Crossing, Bechtel Corporation, July 1965

J. <u>District's position on selection of type of system</u>

In a letter dated March 12, 1965, from Mr. R. A. Skinner, General Manager and Chief Engineer of The Metropolitan Water District of Southern California, to Mr. Alfred R. Golze', Chief Engineer of the Department of Water Resources, regarding the optimum pump-lift system, the following statement was made:

> ". . . Bechtel presented in a letter dated February 23, 1965, specific recommendations concerning the optimum pumping system for the Tehachapi Crossing. I submitted the recommendations presented

in Bechtel's letter and the three reports to the District's Board of Directors at its regular meeting on March 9, 1965, with the recommendation that the reports of Bechtel Corporation be received and filed by the Board, that the recommendations of Bechtel Corporation in the letter dated February 23, 1965, be accepted by the Board as representative of the District's position, and that said reports and recommendations be forwarded to the Department of Water Resources with a statement that the District's Board of Directors urges the Department of Water Resources to accept the recommendations, with the exception that if the Department is of the opinion that a postponement of the decision of a pump-lift system beyond May 1965 would seriously interfere with the scheduling of work on the California Aqueduct, the Department should decide upon a three-lift system in Pastoria Creek for preparation of final plans and in addition start preparation of final plans on a two-lift system as an alternative so that, in the event the testing program establishes that a single-stage pump is suitable for a two-lift system, a change in the type of system can be made without any loss in time insofar as the scheduling of construction is concerned."

Mr. Skinner further stated as follows:

"Considering the entire spectrum of the evidence now available, it appears more logical to accept a three-lift system for the Tehachapi Crossing, based on designs and equipment backed up by experience records of many years of successful operation, rather than a single-lift system for which the principal components necessarily would be designed beyond the present developments, and for which the record does not substantiate that the operation will be as efficient, reliable, and safe as in the case of a three-lift system with single-stage pumps."

In a presentation on May 5 to the California Department of Water Resources and the Tehachapi Crossing Consulting Board on the Tehachapi pump lift, Mr. Skinner stated the following:

> ". . . Metropolitan has taken the position of advocating, first, a three-lift system on the Pastoria Creek location and, second, a two-lift system on the Pastoria Creek or the ridge location, subject in each case to acceptable adaptation to environmental factors of topography, geology, stream flow, and streambed debris transport, among others. As definitive design of the selected system must be initiated promptly, Metropolitan has suggested that design of a three-lift system and of a two-lift system be commenced simultaneously, final selection to be made after the pump research and development program is further advanced."

K. <u>Reports of the Tehachapi Crossing Consulting Board</u>

All of the reports referred to hereinbefore have been submitted to the Tehachapi Crossing Consulting Board which has been retained by the Department of Water Resources to review the reports and to make recommendations to the Department regarding the Tehachapi Crossing.

The Tehachapi Crossing Consulting Board submitted the following letters to the Department of Water Resources:

> Tehachapi Crossing Consulting Board letter of February 21, 1963, to Alfred R. Golze', Chief Engineer, Department of Water Resources

Tehachapi Crossing Consulting Board letter of January 10, 1964, to Alfred R. Golze', Chief Engineer, Department of Water Resources

Tehachapi Crossing Consulting Board letter of May 27, 1964, to Alfred R. Golze', Chief Engineer, Department of Water Resources

Tehachapi Crossing Consulting Board letter of May 29, 1964, to Alfred R. Golze', Chief Engineer, Department of Water Resources

Tehachapi Crossing Consulting Board letter of October 23, 1964, to Alfred R. Golze', Chief Engineer, Department of Water Resources

Tehachapi Crossing Consulting Board letter of December 22, 1964, to Alfred R. Golze', Chief Engineer, Department of Water Resources

Tehachapi Crossing Consulting Board letter of May 8, 1965, to Alfred R. Golze', Chief Engineer, Department of Water Resources

In the last letter listed, the Consulting Board stated the following:

> "No further consideration of the Pastoria Canyon routes is warranted. It is believed that detailed reasons for this position are not required since the recent site explorations adequately support this conclusion. We recommend that future design be devoted to the Ridge single-lift scheme with underground discharge pipes."

II. SCOPE OF COMPARATIVE STUDIES

In making comparative studies of the Tehachapi Crossing the Department of Water Resources and Bechtel Corporation studied alternative systems along the following alinements:

1. Two-lift and three-lift systems in Pastoria Canyon,
2. Single-lift, two-lift, and three-lift systems on the ridge alinement, and
3. Two-lift systems utilizing sites for one pumping plant on the ridge alinement and the other pumping plant in Pastoria Canyon.

The results of these analyses are contained in the Department of Water Resources' and Bechtel's reports listed herein.

Four-stage, single-flow pumps have been considered for the single-lift system; single-stage, single-flow pumps have been considered for the three-lift system; and both two-stage, double-flow pumps and single-stage, single-flow pumps have been considered for the two-lift system. Underground delivery lines and surface delivery lines have been considered for the single-lift and two-lift systems, but only surface delivery lines have been considered for the three-lift system.

In all of the studies the total capacity of all of the pumps installed in each plant is equal to the total conveyance capacity of the aqueduct supplying water to the

Tehachapi Crossing. No spare capacity has been provided over and above that required to deliver the design capacity of the aqueduct in any of the studies. Earlier studies were based entirely upon a tentative design capacity of 5,000 cubic feet per second. Subsequently, a design capacity of 4,100 cubic feet per second was determined and adopted for that reach of aqueduct which includes the Tehachapi Crossing. The studies on alternative systems for the crossing which are contained in the DWR and Bechtel reports dated April and May, respectively, are based on a total installed pumping capacity of 4,100 cubic feet per second.

In the systems along the Pastoria Canyon alinement reservoirs were considered as forebays at each of the pumping plants. On the ridge alinement balancing tanks were first considered in lieu of reservoirs at the second plant of a two-lift system and at the second and third plants of a three-lift system because suitable sites for reservoirs had not been located; however, in the latest studies of a two-lift system, an off-line reservoir located in a nearby canyon was used in the comparative studies.

The geology and seismicity of the areas along the routes of the alternative systems have been extensively studied by the Department of Water Resources, Bechtel Corporation, the Department's Consulting Board for Earthquake Analysis, and the Tehachapi Crossing Consulting Board. The results of these investigations are included in the reports referred to herein. Preliminary designs have been made of pumping plants, dams, forebays and reservoirs, switchyard areas, runoff protection, discharge tunnels, surface discharge lines, balancing tanks and other appurtenances. The designs are shown in various reports referred to in the introduction.

Studies have been made but not carried to completion on motors and valves for the pumping plants. The extensive testing program on the pumps as mentioned in the introduction is still being conducted and it is proposed that the program be carried to completion.

Studies of the power system required to furnish energy for the pumping units have been conducted by the Department of Water Resources and its consultants, the Fluor Corporation, independent of the studies of alternative systems for the Tehachapi Crossing. The studies listed in the introduction do not give consideration to the problems associated with power supply, and for the purposes of this report, it is assumed that an adequate power supply system will be provided for the Tehachapi Crossing.

III. CRITERIA TO BE USED IN SELECTING A PUMP-LIFT SYSTEM

The pumping system to be installed at the Tehachapi Crossing is a critical element of the California Aqueduct in relation to the delivery of water to Southern California. In a news release dated October 25, 1964, Mr. William E. Warne, Director of the State Department of Water Resources, stated in reference to the Tehachapi pumping system that "A pumping task of this magnitude has never before been accomplished." Since the future growth of Southern California is dependent on an adequate and dependable water supply and since the District has entered into a contract with the Department of Water Resources for the delivery of water from the California Aqueduct to meet the demands of the future, it is essential that the delivery of water from the California Aqueduct to the District must be as dependable as possible. Over 80 percent of the water to be pumped over the Tehachapi Crossing for delivery into Southern California will be taken by Metropolitan; therefore, over 80 percent of the cost of the Tehachapi pumping system will be paid for by Metropolitan.

In view of the importance of a dependable water supply, the following criteria should be used in the selection of a pumping system for the Tehachapi Crossing:

A. Reliability

The system must be reliable to deliver water as stipulated under the terms of the Water Service Contract between the Department and the District so that an unfailing water service will be available to Metropolitan and other contractors. Reliability is of the utmost importance.

B. Dependability

The system must be dependable in operation so that water will be delivered to the service contractors as and when required. Dependability along with reliability is of the utmost importance.

C. Efficiency

Because of the high annual power cost, required for pumping quantities of water up to 4100 cfs against a head of nearly 2000 feet, the efficiency of the system must be the highest available that is compatible with reliability and dependability.

D. Cost

The system should not be selected primarily on the basis of the lowest initial cost, the lowest total of all capital costs, or the lowest total of the present worth of all capital, operation, maintenance, and replacement costs. The selection of the system should be on the basis of reliability and dependability. In the course of selecting a system and in the designing of the system selected consideration should be given to the improvement of the reliability and dependability even to the extent of increasing the cost of the project if the improvement warrants such an increase.

E. Controls

The controls for a pumping system are necessarily complex and the control systems must be duplicated and triplicated in order to assure reliable and dependable control of pumping units. However, the complexity of the controls for the pumping system must not be disassociated from those controls on the remainder of the California Aqueduct. A high degree of reliability is required in all of the controls. The reliability of controls for pumping plants and hydroelectric installations has been demonstrated repeatedly in the many plants in operation. Very large plants are currently operated from central stations located as far as a hundred miles away from the controlled station. Controls should be selected only from those which have been tried and proven in actual installations. On the other hand there is very little experience on the remote control of the flow of water in large aqueducts to base the design of controls proposed for the California Aqueduct.

F. Quality control

The control of quality on any system selected must be as rigorous as is possible in order to assure a reliable and dependable system. Therefore, the degree of quality control required in construction of many of the systems must not be related one to the other, but all must be equal. However, the consequences of an oversight in the quality control or the failure to detect a defect must be considered a probability in the comparison of the various types of systems. Furthermore, enforcing rigorous quality control on the actual construction would affect the actual cost. Estimates of costs for comparative purposes should give consideration to those factors. When it is necessary to design a system using materials which are difficult to fabricate and to utilize equipment of a size larger than that previously built, there is less chance of making a reasonable estimate for comparative purpose than where more conventional materials and equipment are used.

IV. AREAS OF GENERAL AGREEMENT

A. Pastoria Canyon

There has been extensive investigation of the geology in the Pastoria Canyon both by the Department of Water Resources and by Bechtel Corporation. The results of these investigations can be summed up by quoting from two reports. In the Department's Report on Alternative Locations of Tehachapi Lift System dated April 1965, the following statement is made in the conclusions on page II-I of Chapter 2:

> "A high degree of risk would be involved in the construction of a conveyance system in Pastoria Canyon due to the existence of extremely poor geologic conditions and steep topography in this area of high seismic potential."

In Geologic Progress Report No. 2 dated April 30, 1965, as issued by Bechtel Corporation, the following statement is made under the conclusions and recommendations on page 2:

> "Geologic conditions in Pastoria Creek are adequate for constructing any of the proposed two- or three-lift scheme dam sites. Some of these conditions are not ideal and more test data on materials in certain areas are necessary to determine proper design criteria."

In the report of Bechtel Studies of Tehachapi Pump Lift as presented by Mr. M. L. Dickinson on May 5, 1965, to the Tehachapi Crossing Consulting Board, the following statement is made on pages 11 and 12:

> "While Bechtel agrees in general that the ridge location is geologically preferable to the Pastoria Creek location, we do not consider that any large degree of difference exists. On the other hand, it would be impracticable, if not impossible, to substantiate our views of these highly complex and intangible conditions in a completely convincing manner. We, therefore, concede that it would not be prudent to adopt a Pastoria Creek location without much more detailed geological investigations."

Furthermore, the Department has had its Consulting Board for Earthquake Analysis and its Tehachapi Crossing Consulting Board review the geology of the Pastoria Canyon and the ridge alinements of the Tehachapi Crossing. In a letter dated April 8, 1965, the Consulting Board for Earthquake Analysis makes the following statement:

> "Thus, we find no reason to modify the conclusion expressed in our report of December 22; that is, while the crossing can be effected by either scheme the Ridge scheme is preferable to the Canyon scheme in that it is less vulnerable to damage and presents less potential hazard to life and property."

The Tehachapi Crossing Consulting Board makes the following statement in a letter dated May 8, 1965:

> "No further consideration of the Pastoria Canyon routes is warranted. It is believed that detailed reasons for this position are not required since the recent site explorations adequately support this conclusion."

It can be concluded, therefore, that the Pastoria Canyon alinement should be eliminated from further consideration for the Tehachapi Crossing of the California Aqueduct.

B. Balancing tanks

Along the ridge alinement balancing tanks with 6 minute storage allowance were considered for multilift systems, both two-lift and three-lift systems. The 6 minute storage allowance was considered to be rather limited for operation of a system as large as that required for the Tehachapi Crossing. In the aforementioned report of M. L. Dickinson the following statement is made:

> "Furthermore, since some concern has been expressed over the possible inadequacy of a 6 minute storage allowance in balancing tanks on multi-lift ridge schemes, we have not carried forward the two-lift and three-lift schemes utilizing balancing tanks which were presented in our January 1965 report. This does not indicate that we consider these schemes inadequate or infeasible. It must be admitted, however, that 30 minute storage capacity is preferable to 6 minute storage capacity."

Therefore, balancing tanks have been eliminated from further consideration.

C. Off-line storage reservoir

An off-line site for the storage reservoir having at least 30 minute storage capacity has been located for a two-lift system on the ridge alinement.

Reservoir sites for a three-lift system on the ridge are not available.

D. Pumps

The Department of Water Resources has contracted with Daniel, Mann, Johnson, and Mendenhall to conduct the research and development program under which three models of pumps were designed and built specifically for conditions that exist at the Tehachapi Crossing under each of three different lift systems. Three pump models were designed and built as follows: A single-stage pump for a three-lift system, a two-stage, double-flow pump for a two-lift system, and a four-stage, single-flow pump for a single-lift system. Preliminary tests have been run on these models and the efficiencies as determined in the model tests are reported in Volume I of the 4 volume report of Daniel, Mann, Johnson, and Mendenhall, titled "Tehachapi Pumping Plant, Comparative Analysis of Lift Concepts, Pumps and Interface Elements" dated April 1965. Relative efficiencies reported are as follows:

Single-stage pumps for three-lift system - highest efficiency

Two-stage, double-flow pumps for single-lift system - next highest efficiency

Four-stage pumps for single-lift system - lowest in efficiency

A review of the installations both in Europe and in the United States was made by Daniel, Mann, Johnson, and Mendenhall and by Bechtel Corporation. DMJM stated in its report of April 1965 that "Regardless of the pump type finally selected, be it a single-stage, two-stage or four-stage pump, there is no doubt whatever that the pump industry will be able to design and build pumps for Tehachapi that will be reliable and will give satisfactory service over the next 50 years." Bechtel Corporation has certain reservations concerning the suitability of certain types of pumps for the Tehachapi pumping system which will be pointed out later. Nevertheless, Professor Hans Gerber, although recommending a two-lift system, made the following statement in his report, titled "Tehachapi Pump Lift System, Additional Remarks on European Pumping Practices" dated May 1965:

> "We think that the choice of a single-lift, a two-lift or a three-lift solution is first of all a topographical, geological and seismic problem. It should be clearly stated that, independent of costs, it would be possible for all three lift solutions to have reliable and rugged pumps built, and for all these pumps long years of experience of different kinds are available."

In July 1965 DMJM recommended a four-stage, single-flow pump, whereas Professor Hans Gerber strongly recommends a two-stage, double-flow pump which he considers most suitable for the Tehachapi Crossing, as will be indicated later.

E. Type of pumping system

From the foregoing the following can be concluded regarding the three types of pumping systems:

Three-lift system - No further consideration should be given to such a system for purposes of the current State Water Project because of the geologic environment in the Pastoria Canyon and because of the lack of suitable reservoir sites on the ridge alinement.

Two-lift system - A favorable two-lift system can be built along the ridge alinement because of the possibility of developing a suitable reservoir on the ridge alinement for such a system. Pumps of higher efficiency can be built for a two-lift system than can be built for a single-lift system.

Single-lift system - Nothing has been presented which precludes the use of a single-lift system on the ridge alinement; however, the pumps for such a system are less efficient than those for a two-lift system and the penstocks require excessive plate thickness.

V. PRELIMINARY RECOMMENDATIONS OF A SYSTEM FOR THE TEHACHAPI CROSSING

A review of the history of the District's involvement in the research and development program on the Tehachapi Crossing indicates that the District has repeatedly recommended that consideration be given a multilift system in addition to a single-lift system for the Tehachapi Crossing. In the quotation on page 18, taken from a paragraph in the letter dated March 12, 1965, to Mr. Alfred R. Golze', the District recommended that a three-lift system for the Tehachapi Crossing should be adopted rather than a single-lift system. In the quotation on page 19, taken from the District's presentation to the California Department of Water Resources and the Tehachapi Crossing Consulting Board on May 5, 1965, Mr. R. A. Skinner, General Manager and Chief Engineer of the Metropolitan Water District, advocated, first, a three-lift system on the Pastoria Creek location and, second, a two-lift system on the Pastoria Creek or the ridge location, subject in each case to acceptable adaptation to environmental factors, and suggested that design of a three-lift system and of a two-lift system be commenced simultaneously, final selection to be made after the pump research and development program is further advanced.

Subsequent to the preparation of the May 5 report, the environmental factors for a three-lift system have been reported as being adverse on either alinement. Pastoria Creek is considered unacceptable for either a two- or three-lift system. Therefore, the District is forced to withdraw from its position of advocating a three-lift system on either the Pastoria Canyon alinement or the ridge alinement, or a two-lift system on the Pastoria Canyon alinement.

VI. RECOMMENDATION THAT A TWO-LIFT SYSTEM BE ADOPTED

The District recommends that a two-lift system on the ridge alinement be adopted for construction on the Tehachapi Crossing using two-stage, double-flow pumps and an off-line dam and reservoir at the second lift, similar to that shown in the Department of Water Resources' Report on Alternative Locations of Tehachapi Pump Lift System dated April 1965, Plate 6, titled System Ridge Two Equal Lift Plan and Profile, with the exception that underground delivery lines be considered in lieu of surface discharge lines and except that the District favors horizontal setting of the two-stage, double-flow pumps.

Eight pumps each of 585 cfs should be installed with shafts in the horizontal arrangement. Thus, seven pumps would deliver 4100 cfs and the eighth pump would be a spare. Each pump should operate at 600 rpm, have a specific speed of approximately 1950, and pump against a total head of approximately 988 feet. The motor would have a rated output in excess of that required for the pump at any point along the curve for a distance of plus or minus 10 percent of the rated head and would have a rating in excess of 72,500 horsepower. The exact horsepower rating should be determined by consideration of results of model tests. This recommendation should not be construed to exclude the use of a larger number of smaller size pumping units.

At the first pumping plant the centerline of the shaft on the pump would be located at least 70 feet below the minimum operating water surface elevation in the forebay, or approximately at elevation 1159. This should result in a suction specific speed of approximately 6500 at the most adverse operating conditions. At the second plant the centerline of the shaft would be placed approximately 70 feet below the minimum water surface in the reservoir or at elevation 2094. The high water level in the reservoir should be at elevation 2229 and the low water elevation should be 2164. With this difference of elevation, there will be ample opportunity for a change in water level in the reservoir and a resulting change in the net head on the pumps to adjust the flow of the pumping units in the first plant at the bottom of the lift with those at the second plant at the reservoir.

A central control room should be provided in the lower pumping plant. The pumping units should be started and stopped by automatic control of starting and stopping sequences after the sequence is initiated by the operator. The automatic starting and stopping sequences should be programmed to permit the starting and stopping of one unit in each plant in accordance with a preset timing schedule thereby avoiding the introduction of the element of human error in the operating procedure.

Supporting data on the recommendation are given on the following pages.

VII. SITE CONDITIONS

A. Geology

1. General statement - In a letter dated May 8, 1965, to Mr. Golze', the Tehachapi Crossing Consulting Board states as follows:

   > "In general, the overall site geology in the Ridge area is favorable and reasonably good rock is found at relatively shallow depths. Geologic conditions are quite similar for the two-lift and single-lift Ridge schemes."

2. Geology at the base of the lift - The Department of Water Resources' report of April 1965 states as follows:

   > "The forebay excavation will be mostly in alluvium which is predominantly silty sand."

   > "Station A Pumping Plant. The pumping plant will be founded entirely upon the Tejon formation which dips 30 to 35 degrees to the northwest and consists of firm sandstone with minor interbeds of siltstone. The alluvium overlying the Tejon formation ranges from 5 to 65 feet in thickness. The depth to static water averages 20 feet below ground surface; no unusual dewatering problems are anticipated. The sandstones will require ripping with possibly some light blasting. Cut slopes should be stable . . . . Limited rock testing indicates the sandstone has adequate strength for the proposed structure. It may be necessary to shift the position of the pumping plant slightly to avoid placing it on weak materials associated with the faults."

Bechtel reports on the geology at the base of the lift in its Geologic Progress Report No. 2 dated April 30, 1965, as follows:

> ". . . the forebay areas, first-lift pumping plants, and portions of the first-lift discharge pipe alignments are underlain by younger rocks with different physical properties."
>
> "These younger strata are (1) volcanic rocks of either Miocene or Oligocene age, (2) the Tecuya formation of Oligocene age, and (3) the Tejon formation of Eocene age. The volcanic rocks are sound lava flows and soft to firm flow breccias. The Tecuya formation is composed predominantly of continental sandstone and conglomerate, some of which appear tuffaceous. The marine Tejon formation is predominantly poorly cemented to friable sandstones."
>
> "The Tertiary formations have been tilted to the north presumably during uplift of the Tehachapi Mountains. They dip irregularly northerly at about 30°. No major faults were found in these Tertiary strata."

3. Geology at intermediate pumping station - The Department of Water Resources makes the following statement in its April 1965 report:

> "Based on current information, the pumping plant will be located on hard, strong, fractured gneissic diorite, and no unusual construction problems are expected."

4. Geology in the off-line reservoir area - The Department of Water Resources further states in its April 1965 report as follows:

> "The proposed 167-foot-high dam will lie in a V-shaped narrow canyon with an extremely steep gradient. Foundation rock consists of moderately to deeply weathered gneissic diorite which is cut by numerous two to five feet wide pegmatite veins. Outcrops are very spotty, and the entire damsite area is mantled by soil with widespread evidence of shallow creep."

In an inter-office memorandum dated June 16, 1965, Bechtel geologist Cole R. McClure makes the following statements regarding the off-line reservoir:

> "1. That the bedrock in the area is hard, relatively fresh dioritic gneiss completely competent foundation rock for any type of concrete or earth fill dam.
>
> 2. That major slides in this area are not probable, even considering that earthquake shock and saturation of areas surrounding the proposed reservoir would occur. This evaluation is based on the fact that the soil cover in the area is quite shallow, generally less than 10 feet, and hence deep seated slides are unlikely.
>
> 3. That soil creep is probable in the area because of its extent and the steep slopes.
>
> 4. That moderately to highly weathered rock generally extends from 10 to 30 feet below the soil cover."

Mr. McClure further states as follows:

> "I do not envision any geologic conditions which would seriously affect the construction of a reservoir in this

area. Furthermore, foundation conditions for a properly designed and constructed dam or pumping plant are suitable."

5. Summary of geology - The Department of Water Resources and Bechtel agree on the above statement. The geology of the upper plant and reservoir is more favorable than that for the lower plant and forebay. While it is not possible to eliminate the use of the lower site for any system along the ridge alignment it is possible to reduce the number of pumping units at the lower plant by using the two-lift system.

B. Seismicity

In a letter dated May 8, 1965, to Mr. Golze', Chief Engineer of the Department of Water Resources, the Tehachapi Crossing Consulting Board makes the following statement:

> "Both schemes have the same exposure to shaking and fault rupture. The probability of actual displacement is very low, but the area may be severely shaken several times during the life of the project."
>
> "Here again the location of the structures and the number of structures are important. The two-lift scheme, having over twice the number of structures, offers over twice the chance for seismic damage."

The Consulting Board for Earthquake Analysis stated the following in a letter dated April 8, 1965, to Mr. Golze':

"We feel that there is insufficient information available to us at the present time to justify specific differentiation between the several schemes on the basis of earthquake hazard. Thus, we limit our main considerations to the two basic plans for effecting the Tehachapi Crossing - - the Pastoria Canyon scheme and the Ridge scheme."

"In our opinion, the information does not warrant any more specific statements than those presented in our report of December 22, 1964 . . . ."

"Thus, we find no reason to modify the conclusion expressed in our report of December 22; that is, while the crossing can be effected by either scheme the Ridge scheme is preferable to the Canyon scheme in that it is less vulnerable to damage and presents less potential hazard to life and property."

"Furthermore, in connection with the Ridge scheme, we prefer the use of tunnels in sound rock to surface installations in weathered material on steep slopes."

"We would like to reiterate a statement from one of our previous reports that the overall reliability of any scheme will often depend more on the detailed treatment of the engineering problems involved than on the inherent hazards of any single general alignment."

1. Lower pumping plant - While the geology at the location of most structures on the ridge alinement is of reasonably good rock, the geology at the lower plant is located on Tejon sandstones. The Consulting Board for Earthquake Analysis stresses the importance of placing the discharge tunnels in good rock.

2. Upper pumping plant and off-line reservoir site - In the aforementioned letter of May 8, 1965, the

Tehachapi Crossing Consulting Board states the following:

> "The possibility of damage to the small off-line reservoir due to shaking, overtopping waves from seismically triggered landslides, or partially filling the reservoir with slide debris, is ever present even during light shocks which are more numerous than major shocks."

Mr. Cole McClure, geologist for Bechtel, referred to the seismic hazard in an inter-office memorandum dated June 16, 1965, which is quoted under Section VII A-4. He suggests a treatment for preventing debris from entering the reservoirs as follows:

> "It is my opinion that the possibility of large landslides in this area is remote. Small surficial slides, or soil creep, are expected to be minor maintenance problems. The areas of potential soil creep can be controlled by the use of interceptor channels which would prevent the debris from entering the reservoir or by some other of the numerous methods of slope stabilization."

3. Pumping units - The Tehachapi Crossing Consulting Board, in a letter of December 22, 1964, to Mr. Golze', states the following in regard to design details:

> "The degree of safety and reliability of any lift systems will be a function of exposure both to seismic effects and to accidental malfunctions. The more elements that are involved in a lift system, which is inherently a series arrangement, the greater is the probability of damage or unscheduled

> shutdown. The elements include station structures, discharge lines, tunnels and storage reservoirs, as well as pumps, motors, auxiliaries, control systems and power supply. The system with the lesser number of these elements has an inherent advantage in reliability."

There would be 16 units in a two-lift system as compared with 14 units in a single-lift structure, including a spare unit in each pumping plant. There is very little difference in the number of pumping units; however, one-half of the units in a two-lift system would be located on good rock as compared to locating all of the pumps for a single-lift system on the Tejon formation.

4. Two-stage, double-flow pumps - Damage from seismic accelerations would be less on a two-stage, double-flow pump mounted with the shaft in a horizontal position than on a four-stage pump with the shaft mounted in a vertical position and supported at the motor base, at the pump casing by bolted connections, and at the base of the pump on a pedestal.

VIII. DISCHARGE LINES

A. Underground versus surface discharge lines

Underground discharge lines are recommended because of the increased safety and dependability over surface discharge lines. In a letter dated April 8, 1965, to Mr. Golze', the Consulting Board for Earthquake Analysis states as follows:

> "Furthermore, in connection with the Ridge scheme, we prefer the use of tunnels in sound rock to surface installations in weathered material on steep slopes."

In a letter dated May 8, 1965, the Tehachapi Crossing Consulting Board makes the following statement regarding discharge lines:

> "Explorations have indictated that the discharge lines can be located in tunnels in hard and strong gneissic diorite rock. Considering seismic effects and reliability in operation and maintenance, discharge lines in tunnels are preferred for safety and dependability over surface installations which, in some locations would be in weathered or sheared material on steep slopes."

In the latest studies by both the Department and Bechtel, the capital costs are higher for systems with underground discharge lines than for comparable systems with surface discharge lines.

In constructing the underground discharge lines, steel liners would be placed in the tunnel bored for the lines and the space between the liner and the tunnel walls would be filled with concrete. The loading which could be taken by the rock can be determined only after the tunnel has been bored and readings taken. The steel liner should be designed for external pressure conditions as outlined in Chapter 3 on page 10 of the Report on Alternative Schemes for the Tehachapi Crossing of the California State Water Project, dated September 1964, as prepared by Bechtel Corporation.

B. Type of steel

In a report on discharge pipes for the Tehachapi Crossing by Alexei P. Maradudin, Consulting Metallurgist, dated October 1964, a recommendation is made on page 11 as follows:

> "The ASTM A-516 Grade 70 and Lukens Penstock Class A and B steels are recommended for the intermediate and high pressures. In order to obtain the best results, pipe fabricated from these steels should be preheated for welding, 100 per cent radiographed, stress-relieved and hydrostatically tested after welding. There should not be any welding after stress-relieving. In purchasing these steels a notch toughness guarantee should be required. Each plate should be tested longitudinally and Charpy V-notch impact strength should be 30 ft. lbs. on a minimum average of three specimens at +10°F. The minimum value for a single specimen should be 25 ft. lbs."

In the Department's Report on Alternative Locations of Tehachapi Pump Lift System dated April 1965, ASTM A-285 Grade C steel is listed for use in the low pressure sections of the discharge line. On page 6 of the aforementioned report of Mr. Maradudin, he states the following:

> "The ASTM A-285 Grade C is of firebox quality, while the A-442 Grade 60 is of flange quality. A-285 Grade C has good properties and is extensively used for boiler and pressure vessel construction. It has excellent welding characteristics and requires only limited preheat. Preheat is required only to dry out the moisture if the atmospheric temperature is below +40°F or if plate thickness is over 1". Although this steel, by implication is approved by Section VIII of the ASME Code for use in temperatures as low as -20°F, it was found that it can be brittle at temperatures considerably higher. The above mentioned cases involving the Anderson Ranch penstock and the Tidewater Refinery pressure vessel failures substantiate this. A-442 Grade 60 is a flange quality steel and is supplied in thicknesses 1" and below. In purchasing both of these steels, guaranteed notch toughness should be required. This guarantee should specify that <u>each plate</u> should have a Charpy V-notch strength of 20 ft. lbs. minimum average of 3 specimens at +10°F. Charpy specimens to be taken longitudinally and the minimum value for a single specimen should be 15 ft. lbs. The welding specification should cover stress-relieving, 100 per cent radiographic and hydrostatic testing, and no field welding after stress-relieving."

C. Repairs to discharge lines

Repairs to underground discharge lines are difficult because of the concrete backing to the steel liners. Satisfactory repairs require cutting through the discharge pipe, chipping out the concrete beyond the area to be repaired, and putting in patching plates with an access hole to permit movement of personnel from the inside to the outside of the steel liner. After the steel plate is repaired the concrete should be replaced behind the steel liner. The repairs to surface lines are much easier to make; however, the hazard appears to be greater to surface lines according to the statements given under paragraph D.

D. Quality control

It is essential that there be rigorous control of quality of the steel plate, fabrication of the steel plate for field welding, testing of fabricated sections and the nondestructive examination of the welds in order to insure that the discharge lines will be of the highest quality possible. Reliability can be obtained by carefully selecting material and controlling the quality of both the material and the fabrication during the construction of the discharge line.

E. Manifolds

The studies have produced few recommendations regarding the manifolds. In all probability model testing of the manifolds would be desirable.

F. Number of discharge lines

An equal division of eight pumps in each plant of a two-lift system can be made if two discharge lines are constructed. A single discharge line could be used with the eight units; however, the Department makes the following point in its Report on Alternative Locations of Tehachapi Pump Lift System dated April 1965 on page III-42 under the heading of Discharge Tunnels:

> "The number of discharge tunnels was selected as two. This was considered as a minimum in order to avoid complete shutdown of water deliveries for reasons of maintenance or emergency repairs to either tunnel."

With two discharge tunnels an outage of one tunnel for maintenance or emgergency repairs would reduce the output of the plant to not less than 4/7 of the total, if four pumps continued operational for delivery to the line remaining in service.

X. MECHANICAL FEATURES

A. Pumps

Two-stage, double-flow pumps are recommended for the two-lift system based on a review of the information contained in the reports prepared by DMJM and Bechtel Corporation.

The results of extensive surveys of existing pumping installations are covered in Volume III of DMJM's report of April 1965, titled, "Investigation of high head pumping practice in Europe and the United States," and by Bechtel Corporation in an interim report on European pump practice in connection with studies for the Tehachapi Crossing of the California State Water Project, prepared by Professor Hans Gerber, Consultant, and Dr. Robert A. Sutherland, Consultant, dated October 1964, and in a second report of the same title and prepared by the same consultants dated January 1965.

In addition to the surveys of European and American practices, tests have been made on model pumps by three manufacturers under contract with DMJM and the Department of Water Resources. Other tests have been made by Bechtel Corporation at the National Engineering Laboratory, East Kilbride, Scotland, on existing pump models obtained from pump manufacturers in an effort to obtain certain basic data on pumps being considered for the Tehachapi pump lift.

Data collected in the survey disclose that the two-stage, double-flow pump with shaft in the horizontal arrangement has an outstanding record. In every point evaluated, the two-stage, double-flow pump is superior to a four-stage, single-flow pump. In all points evaluated other than simplicity and efficiency, the two-stage, double-flow pump with horizontal shaft also is equal to or better than the single-stage, single-flow pump.

At the present time, the records of operation of single-stage pumps at heads approximating that in each lift of a two-lift system at Tehachapi are not of sufficient length to justify the selection of such a pump for the two-lift system. However, the results of tests being conducted by Bechtel Corporation on single-stage pumps for a two-lift system should be considered before issuing specifications for the pumps.

Data supporting the selection of a two-stage, double-flow pump can be summarized under the following headings:

1. Efficiency - A substantial effort has been made to accumulate data on the efficiencies of various types of pumping units which are in service at the present time. The data have

been reviewed in an attempt to determine the efficiency which can be expected for the Tehachapi pumps based on the efficiency obtained from model tests.

There is a lack of adequate and authoritative tests on both field installations and on representative model pumps to permit any comprehensive study. In a letter dated March 9, 1964, Mr. Alfred R. Golze', Chief Engineer of the Department of Water Resources, reported on the results of discussions held by Daniel, Mann, Johnson, and Mendenhall with four manufacturers of pumps who were prospective model test contractors. He stated that several points were advanced which confirmed previous conclusions, one of which was as follows:

> ". . . none of the four pump companies who made proposals were willing to indicate what step-up in efficiencies could be guaranteed between the model and the prototype for the various types of pumps. This was very discouraging in view of the fact that we are primarily interested in how the various prototype pumps will perform and not specifically in what the model pumps alone will do."

In a letter dated March 18, 1964, the District replied to Mr. Golze's point as follows:

> "The District is well aware of the fact that the step-up in efficiencies is a matter of conjecture and cannot be proved to any degree of finality because of the difficulty in accurately measuring flows through large size pumping units. For this reason a true comparison of single-stage and multistage pumps can only be made where the head, capacity, and horsepower can be reliably measured, as in a testing laboratory, and there only can models of pumps of the size being considered for Tehachapi Crossing be tested."

The testing of model pumps in manufacturers laboratories has provided data which gives more information on the efficiencies of the various types of pumps being considered for Tehachapi than any other data collected. In the tests, the two-stage, double-flow pump showed a higher efficiency than was predicted at the outset of the tests and 2-1/2 percent greater than that of the four-stage, single-flow model pump in the preliminary tests. The exact efficiencies are quoted in the report of DMJM dated April 1965 in Chapter 9 of Volume I.

A preponderance of the evidence contained in the confidential data collected but not published indicates that the model efficiency might well be taken as the prototype efficiency or at the most an increase of 1 percent may be expected in the prototype pump regardless of the size. Models of the pumps used on the Colorado River Aqueduct were tested at the California Institute of Technology prior to fabrication of the three original pumps in each of the five plants. After the prototype units were installed in the pumping plants, they were field tested using the utmost care to measure head, flow, and power input as accurately as possible. Results of the field tests showed efficiencies only slightly better than the efficiencies obtained in the laboratory tests of the model pumps. The maximum increase in efficiency was 0.5 percent.

Professor Clifford P. Kittridge, Consultant to DMJM, makes the following statement in Volume II, Chapter 8, page 1 of the DMJM report of April 1965:

> "Most of the models have been built and tested by the firms that have designed and built the prototype machines and the details of the model tests have remained their property. Individual manufacturers have been understandably reticent to release the volume of numerical data necessary either to test formulae already proposed or to develop better ones. Several formulae, such as those due to Moody and to Ackeret, were developed by individuals having access to the records of a particular manufacturer.

Thus each such formula was designed to fit the data on which it was based and appears to have done so very well. It is most likely that individual practices in the construction and testing of models has differed so much that no single formula can be expected to have universal applicability. A number of formulae have been proposed on a basis of limited theoretical considerations with few if any numerical data to support them. Moody in particular . . . has warned against placing too much reliance on any formula which has not been substantiated by a large number of tests. It may be concluded that any formula or method for converting the efficiency of a model to that of a prototype machine should have received such substantiation before being applied to an installation as important as the Tehachapi pumps."

The field efficiencies on units in plants listed on Plate I of the Appendix of Volume III of the DMJM report are as follows in a decreasing order for the more efficient units:

Name of plant	Specific speed	Efficiency 2-stage double-flow pumps - %	Efficiency 3-stage or more single-flow pumps - %
Herva	1480	91.5	-
Vianden	1898	91.0	-
Limberg	1230	90.1	-
Lunersee	1500	-	89.5
Motec	1270	-	89.0
Lunersee	1500	-	88.7
Arolla	2550	88.0	-
Etzelwerk	1510	-	87.0

Guaranteed efficiencies that have not been checked by field tests are not tabulated in the comparison herein.

Both the model tests and the field tests show that the two-stage, double-flow pump has the advantage of being significantly more efficient than the four-stage pump.

2. Reliability - Volume II, Chapter 7 of DMJM's report covers reliability. In all of the tabulations concerning pumps alone, the two-stage, double-flow pump is listed as being more reliable than the four-stage, single-flow pump. Such tabulations include total failures, the amount of time for unscheduled outages, and predicted component mean life if the variations are considered in the component mean life.

In the second report on European pump practice in connection with studies for the Tehachapi Crossing of the California State Water Project dated January 1965, and prepared by Professor Hans Gerber, Consultant, and Dr. Robert A. Sutherland, Consultant, the following statement is made under Conclusions and Recommendations on page 38:

> "The greatest experience of successful operation of large pumps in Europe is in the <u>double suction</u> <u>two stage type</u>. Many pumps of this type comparable to those considered for the two lift solution have been operating over extended periods.

> This type should be favorably considered for the two lift solution."

In comparison, Gerber and Sutherland make the following statement concerning four-stage, single-flow pumps:

> "Large pumps of the <u>single suction four or more stage type</u> have never yet been built with the capacity and specific speed combination proposed for the single lift solution, but experience with five-stage Ponale and Lunersee pumps, of approximately half the capacity proposed and with much lower specific speed, has been very satisfactory. The <u>large step forward</u> involved in the proposed <u>one lift solution</u>, particularly in specific speed, should not be taken without adequate supporting model test information."

Of the plants tabulated in the reports by DMJM and Bechtel, five plants have two-stage, double-flow pumps which are comparable to those required for Tehachapi and which have been in successful operation for ten years or more. Two plants have two-stage, double-flow pumps which have been installed for more than 30 years.

It can be concluded that insofar as a pump is concerned, the two-stage, double-flow pump is reliable and has an experience record which is equal to or greater than that of any other type of pump of the large size required for Tehachapi.

3. Cost - The cost of a full complement of pumps in the two plants of a two-lift system is very nearly equal to that of the full complement of the pumps in the one plant of a single-lift system. The total cost of two-stage, double-flow pumps for the two-lift system is shown to be slightly higher in the DMJM report of April 1965 in comparison with the total cost of four-stage pumps. Bechtel Corporation shows a slight advantage for the two-stage, double-flow pumps over the four-stage pumps in its report of May 1965. The cost of the pumps is only one factor in the total cost and the relative costs of all systems are approximately the same. Reliability and dependability are considered of more importance than cost in making the final selection of a pumping system.

4. Maintenance - In Volume I, Chapter 6 of the DMJM report of April 1965, the following statement is made on page 42 regarding the relative maintenance requirements of the various types of pumps considered:

> "Maintenance of the single-lift concept is distinctive mainly because of the required thrust balancing devices and the size of the units. Thrust balancing labyrinths generally are replaced more often than wear rings so that the four-stage prototype pump should require a

greater number of scheduled maintenance actions than the other prototypes. The fact that four stages must be maintained makes pump overhaul repair time longer for the single lift than the three-lift."

In the two-stage, double-flow pump there are three impellers because the second stage of each half of the symmetrical pump are combined into one impeller in the middle to discharge into one volute.

DMJM shows in Chapter 7 of Volume I the two-stage, double-flow pump mounted with the shaft in the vertical similar to the four-stage, single-flow pump. In an interim report, titled "Investigation of High Head Pumping Practice In Europe" dated October 1964, page 5, DMJM compares a horizontal shaft arrangement with a vertical shaft arrangement on pumping units as follows:

> "Of the twenty-three pumping plants included in this report, six contain vertical units while seventeen have pumps with a horizontal shaft arrangement. The latter includes Vianden where nine horizontal units with a pump rating of 93,400 HP each are installed in an underground station."
>
> "Where general conditions favor a horizontal shaft installation, that is where the pump inlet pressure conditions are generous and where topography is favorable, this type of plant is much preferred by the operators. With all of the major operating equipment and controls located on one floor level,

the supervision and maintenance work is obviously simplified. The maintenance hours for overhauling and the outage times for this work are considerably reduced."

"It is also noted that the horizontal type units of the two-stage, double flow pumps on which inspections were made, seem to have a better operating record than the vertical units of this type."

In a report by Professor Hans Gerber, titled "Tehachapi Pump Lift System, Additional Remarks on European Pumping Practices" dated May 1965, Professor Gerber states the following, starting on page 6:

"7. <u>Shaft Position</u> - I know that for the Tehachapi plant vertical shaft position has been provided. This solution will surely be the right one for single-suction pumps, both single-stage or even double-stage, overhung."

"If the double-suction, double-stage pump type is to be considered, then both positions of shaft have been chosen; a few only with vertical shaft, mainly Oberaar with a natural high submergence, Ffestiniog and Villa Gargnano, where in both plants the upper runner would better have the position of the lower one."

"8. <u>Maintenance and Operation</u> - Generally speaking, it is considered that for operation the horizontal shaft solution brings some advantages. I would agree with this general opinion as the whole unit is on the same floor. On the other hand, vertical shaft units do not require as much floor space as those with horizontal shaft. But even in underground stations, quite often horizontal shaft machines can be seen."

"Especially for double-suction pumps, the advantage of horizontal shaft position is generally considered to be important."

"Referring to this special type of pump, I must mention the horizontal splitting of the housings, where the sealing of the two parts seems to be resolved. Wherever these split housings are adopted - in Bringhausen, Provvidenza, Limberg, and now in Vianden - the plant operating staff is convinced of the many important advantages of this solution."

"I personally am convinced that with all shaft positions and types of pumps suitable for the Tehachapi project, the horizontal splitting of housings would lead to the best conditions for maintenance, overhaul and repair work, especially also for the exchange of seal rings."

Both DMJM and Professor Gerber report that the two-stage, double-flow pump with shaft in the horizontal position and a split housing the maintenance is preferred by operators over the same pump with a shaft in the vertical position.

The additional maintenance of the balancing labyrinth on the four-stage, single-suction pump for the single-lift solution is correctly pointed out.

Thus, it can be seen that the two-stage, double-flow pump has the advantage in regard to maintenance.

5. Overhaul plan - With a spare unit so that the capacity of the inlet and outlet conveyance

facilities at the Tehachapi Crossing can be handled with 7 of the 8 pumps, maintenance work and checking of pumping units can be accomplished one at a time without interfering with the operation of the California Aqueduct under full design flow conditions. Thus, reliable and dependable operation can be obtained by providing proper maintenance and overhaul schedules on the pumping units.

With the split casing on the two-stage, double-flow pump installed with horizontal shaft the top half of the casing can be unbolted and readily removed with overhead cranes, and the clearances in the bearings, the seal rings between impellers, and the general condition of the entire unit can be readily inspected. Then, if necessary, the shaft and impellers can be lifted vertically as a unit without difficulty by the overhead crane and then moved to a dismantling bay. In reassemblying the unit every part can be checked to ascertain that it is in the right position, that clearances are proper, and that the alinement is correct before the top cover is replaced and secured by the bolts.

During this maintenance work on the pump, the motor can be left undisturbed and the alinement of the motor and pump will not be disturbed because the base of the pump would remain bolted in the position where it was placed during the initial alinement of the unit.

In the dismantling of a four-stage pump, it is necessary to remove the entire pump horizontally to a dismantling bay thereby disturbing the original alinement, or, in the event that the casing is imbedded in concrete, it is necessary to remove the shaft and impellers vertically from the casing. To accomplish this, an intermediate shaft of a length greater than that of the shaft to which the impeller is assembled is necessary between the motor and the pump to permit removal of the shaft and impeller assembly without removing the rotor of the motor, and a special crane for handling of the pump shaft assembly in the restricted space must be provided. Otherwise, dismantling of the four-stage pump can be done only by removing the rotor of the motor and pulling the impeller and shaft assembly out through the center of the motor stator in which case there is always the risk of damage to the motor. In the reassembly of the motor after the repair of a pump, there is always a risk that some change in alinement or fit will be introduced which will cause a subsequent failure or unacceptable operation of the motor when returned to service.

Overhaul of a two-stage, double-flow pump with a shaft in the horizontal position is much simpler than the overhaul of a four-stage, single-flow pump with the shaft in the vertical position.

6. Ability to start with pump casing dewatered - While the method of starting the pumping units has not been determined as yet, it is recognized that there may be difficulty in starting the motors across-the-line with pump casings full of water. The two-stage, double-flow pump mounted with the shaft in a horizontal position can be started in air as is done at Vianden pumped storage plant in Luxembourg. Compressed air is injected into the casing at Vianden to depress the water level below the lowest point of the impeller. Water for lubrication and cooling is supplied from an external source to the seal rings during operation of the pump in air. After the pumping unit is at the full speed, water is introduced into the casing slowly by releasing

the air. Reference is made to this method of starting in the report on Vianden in Volume III of the DMJM report dated April 1965. The units are stopped and started from a control center approximately a hundred miles away. The starting operations are entirely automatic so that the operator at the central control room is only required to close a switch initiating the starting sequence to place a unit in full operation. The two-stage, double-flow pumps at Vianden operate against a head of approximately 880 feet and have a capacity of about 800 cubic feet per second each. A total of 92,800 horsepower is required to operate each pump.

A four-stage, single-flow pump has not been started in air and then filled with water after it reaches synchronous speed according to the reports on the plants visited. Several of the manufacturers are unwilling to recommend such a procedure for a four-stage, single-flow pump mounted with a shaft in the vertical position because of the potential shock at the time water is introduced to the pump.

In Volume II of the DMJM report under Chapter 4, page 9, alternative methods of starting the pumping units are listed. Method b is one in which the motor is started with reduced voltage and with the pump casing dewatered. Method c utilizes a special starting motor to bring the unit up to speed with dewatered pumps. In commenting on these two methods, DMJM states as follows:

> "Methods b. and c. have the disadvantage of requiring the pumps to be dewatered, which is undesirable for any of the pumping schemes and particularly so for the use of four-stage pumps used for the single-lift arrangement. Theoretically, method c. could be used with a watered pump but the starting motor would be of such a large size as to prohibit its use."

The two-stage, double-flow pump has a significant advantage in that the horizontal installation of the unit will withstand seismic accelerations with less damage than will a four-stage, single-flow pump installed with the shaft in the vertical position and supported at the motor by a bracket at the top of the pump and by a pedestal at the bottom of the pump.

7. Balanced thrust - In reference to a two-stage, double-flow pump, DMJM states the following in Volume I, Chapter 7, page 6:

> "The pump is completely symmetrical so that no significant hydraulic thrust need be feared in the axial direction."

Professor Hans Gerber states in his report dated May 1965 that in a two-stage, double-flow pump "The hydraulic axial thrust is practically fully balanced." This characteristic of balanced thrust is opposite to the characteristic of the four-stage, single-flow pump as described in Volume I of the DMJM report, Chapter 6, page 34, as follows:

> "The four-stage pump has a balancing ring for hydraulic thrust control and normally operates with approximately 57 tons total load (hydraulic thrust + weight of rotating parts). At start-up, the load may reach 90 tons, so a thrust bearing in the motor of 100-ton capacity will be needed. Final design will require a check on weights of all rotating parts, as the intermediate shaft length may vary some and the motor rotor weight will be known with greater accuracy."

The elimination of a balance plate and a thrust bearing by the use of two-stage, double-flow pumps will greatly increase the reliability and dependability of the pumping system and will reduce the maintenance over that of a system using four-stage pumps.

8. Effect of wear in pump due to silt in water - In Volume II of the DMJM report, Chapter 10 describes a wear test program being conducted at the intake to the Tracy pumping plant on the Delta-Mendota canal near the intake of the Delta pumping plant which will supply water to

the California Aqueduct. Water samples tabulated in Chapter 10 show that suspended solids are present in the water. In Volume I of the DMJM report there is a statement giving the conclusions and recommendations of the Technical Advisory Board of DMJM. Under point 4, Wear Test Program, the following statement is made:

> "Results obtained to date from the wear test program being conducted under supervision of the Department and DMJM at the Tracy Facility show that this program will be extremely beneficial for determining wear rates of various pump wearing element materials. They show that the water at this location is abrasive. Tests indicate so far that the wear is a function of both sample hardness and water velocity (for a given water quality) and the tests prove that the proper selection of materials will be extremely important."

The relation of this wear test program to the wear in a pump can be noted by the following statement in Volume I of the DMJM report, Chapter 6, page 41:

> "Most important of all records which should be kept but are usually neglected are those regarding water quality. Periodic samples should be taken. Water pH should be monitored and the sample should be weighed and filtered. The filtered residue is weighted to give weight of undissolved solids per unit weight of water. If possible, several grades of porosity should be used in filtering to determine average size of

undissolved solids. Acid tests might be used to distinguish limestone content from quartz or sand. If records such as these were kept at every plant, effects of water quality on wear would soon become apparent."

The report continues as follows:

"4. <u>Maintenance</u>

Maintenance of the single lift concept is distinctive mainly because of the required thrust balancing devices and the size of the units. Thrust balancing labyrinths generally are replaced more often than wear rings so that the four-stage prototype pump should require a greater number of scheduled maintenance actions than the other prototypes. The fact that four stages must be maintained makes pump overhaul repair time longer for the single lift than the three-lift."

On the same page it is further stated:

"For these estimates, it was assumed that balance labyrinths, wear rings, and interstage seal rings are made of 1020 or 1040 carbon steel. Forthcoming results from the wear test program will be used to determine pump operating time between repairs for other material selections."

DMJM describes the two-stage, double-flow pump in Volume I, Chapter 7, page 6, under <u>Balance and Seal Design</u>, as follows:

"The shaft is sealed off by a sliding ring type seal. As clean pressure water is channeled into the space between the two sliding rings, a liquid film is created between the pressure surfaces so that these surfaces are not subjected to mechanical wear, while the sealing surfaces are effectively cooled. A small constant amount of water permanently leaks past the seal into the pump suction bend, thus preventing the ingress of dirty water, which in this way is kept from the sliding ring type seals. Hence, these sliding ring type seals will operate satisfactorily even with dirty water."

In a telegram dated May 25, 1965, responding to a cable from Bechtel Corporation, J. M. Voith states the following:

> "Dependability with clean water and adequate negative suction head the same with all types. With sand carrying water 2-stage pump most favorable. Less favorable the 4-stage pump because of increased wear of clearances for compensation of hydraulic thrust. Less favorable also single stage pump because of wear of clearances and blading resulting from higher stage delivery head."

The two-stage, double-flow pump is the most favorable type of pump for operation without excessive wear, maintenance, and loss of efficiency with water containing abrasive materials, such as may be expected at Tehachapi. The use of a four-stage, single-flow pump would result in a less reliable and dependable system.

9. Experience - In Volume I, Chapter 7, page 23, of the DMJM report the precedent for operation and maintenance of two-stage, double-flow pumps is given as follows:

"The two-stage, double suction pump appears in more large European pumping plants than any other type. Twelve of the 29 plants visited there featured these pumps and four more had double suction single-stage units (see Chapter 2, Volume II and Volume III). Four plants featured double suction pumps in vertical positions. There appears to be no precedent for two plants operated in series using these pumps, but the Hausern-Witznau-Waldshut complex uses two-stage, single-suction pumps in series with forebays at each plant. Operating head for most of the two-stage pumps surveyed is comparable to that planned for Tehachapi. Horsepower on four of the two-stage pumps exceeded the Tehachapi figure. In fact, power range from 83,000 HP to 93,000 HP on these pumps."

In Volume I, Chapter 6, page 36, DMJM gives a precedent for four-stage, single-flow pumps as planned at Tehachapi as follows:

"Precedent established in installed systems throughout the world for the one lift concept's single flow, multistage pumps as planned at Tehachapi is more limited than that for the two lift concept's double suction pumps. Experience with both the one lift and two lift concept pumps surpassed that for the three lift. Information from twelve plants featuring single suction multistage pumps provides a major portion of the basis for this report. (see Chapter 2, Volume II). Three of these twelve pumps have vertical posture and only one required power comparable to the 75,500 HP planned for Tehachapi (58,000 HP at Lunersee). However, eight other plants surveyed had motors exceeding 50,000 horsepower and twenty in all used the vertical arrangement. The number of stages used in the single suction, multistage pumps surveyed ranged from

> two through nine with one being a four stage pump. Heads <u>per stage</u> varied from a low of about 270 feet to a high of 770 feet with a majority of them being in excess of the 500 foot Tehachapi prototype head."

Of the twelve plants featuring single-suction, multistage pumps, six of the plants had pumps with two stages only, the other six plants had pumps of three or more stages. The two-stage pump is basically one-half of the two-stage, double-flow pump, and should not be entirely associated with single-suction multistage pumps.

Professor Hans Gerber in a report on additional remarks on European pumping practices dated May 1965, states the following on page 4 in regard to double-stage, double-suction pumps:

> "For all these questions, in my opinion, this type of pump, which has been developed to a high standard in Europe for more than 30 years, would answer in the very best manner. The following facts may be mentioned: 5.2.1 - There would not be necessary any extrapolation, neither for head nor for size, power or speed. All the Tehachapi conditions are covered with the experiences of about 68 different pumps in almost 30 plants. 5.2.2 - The hydraulic axial thrust is practically fully balanced. I know that for a vertical shaft solution, as provided for Tehachapi, this is of no great importance, but I shall come to this question later. 5.2.3 - The efficiencies have proved to be reasonably high, both on models and on the prototypes,

> and they are still suitable to be increased by going to a somewhat higher specific speed. 5.2.4 - This type of pump can be designed exactly for the same reliability and the same ruggedness as a single-stage, single-suction pump, especially due to the fact that the head per stage is half the value. 5.2.5 - The necessary submergence for good cavitation conditions will be considerably smaller than for the single-stage type, even if we remember that because of the shaft going through the entrance bends some additional submergence would be necessary."

At the Herdecke pumped storage plant in Germany, two-stage, double-flow pumps were installed in 1930 to operate against a head of 508 feet and to pump 494 cubic feet per second and requiring 32,100 horsepower input. These units have operated over 83,000 hours and the experience record on the pumps is excellent as indicated in DMJM's report, Volume II, Part 1, pages 2 and 5.

There are two outstanding installations of two-stage, double-flow pumps in Europe; namely, Vianden pump storage project in Luxembourg and Ffestiniog pump storage project in Wales. The pumps in these plants share honors as requiring the largest horsepower input of any pumps in the world. Ffestiniog pumps require a horsepower input of 94,000 and pump 745 cubic feet per second against a head of 1,000 feet.

Vianden pumps require a horsepower input of 89,000 horsepower each and pump 803 cubic feet per second against a head of 879 feet.

The outstanding example of pumps with more than three stages is that of Lunersee pump storage project in Austria. Each pump requires a horsepower input of 58,000 horsepower and pump 144 cubic feet per second against a head of 3,151 feet. The characteristics of the pumps given here are taken from Plate 1, Chapter 2, Volume II of the DMJM report. Other plants using pumps of three or more stages have the characteristics and operating experiences as follows:

Plant	Horsepower input hp	Flow cfs	Head feet	Year installed	Hours of oper.
Tremorgio	6,800	16.5	2,953	1925	82,000
Ponale	31,500	130	1,903	1940	38,476
Motec	30,300	115	2,065	1959	7,923
Etzelwerk	19,200	92	1,575	1947	29,202
Tierfehd	22,100	97	1,755	1963	700

The experience record on the two-stage, double-flow pump is much more impressive than that on the four-stage pump.

10. Tests - The model testing program being conducted by DMJM for the Department of Water Resources has not been completed but certain preliminary information is given in the DMJM report of April 1965 which is of interest. In a chart, titled "Observed Cavitation" used by DMJM in oral presentations the results of cavitation tests performed on the Sulzer four-stage pump are shown. Inception of cavitation was noted through the viewing window at a suction specific speed of approximately 6,300. DMJM preliminarily recommended a suction specific speed of 7,000. At approximately 7,200 the cavitation was noted to have formed a band about half an inch wide. At 8,000 suction specific speed the band had increased to a width of one and one-half inches. At approximately 9,600 cavitation extended across the vane and at 10,400 there was full cavitation according to the chart.

In Volume II, Chapter 3, page 40 of the DMJM report, the following information is given:

> "The Hydraulic Institute, in its 1961 review, offers several curves relating submergence (or suction lift), pump stage head, and Upper Limits of N_s for hot water, cold water, and for double suction, single suction with shaft through eye, and single suction overhung impellers.

These curves converted to values of S [suction specific speed] give quite a scattering of recommendations. S varies slightly with N_s by these Hydraulic Institute recommendations. Older Hydraulic Institute recommendations gave a general value of S of about 7,900 and S = 8,000 is often quoted as a good "rule of thumb". The latter Hydraulic Institute curves give:

a. S = approximately 8,600 for single suction impellers with shaft through eye and N_s = 2,000;

b. S = approximately 8,300 for double suction impellers with N_s = 2,000 (value based on 1/2 Q equivalent to single suction);

c. S = approximately 9,000 for single suction overhung with N_s = 2,000; all for water at 85° and sea level. Thus, the Hydraulic Institute would rate single suction overhung (c) as slightly better than "with the shaft through the eye".

"In any event, it must be remembered that the Hydraulic Institute recommendations are "upper limits" and are based on breakdown and not on completely cavitation free operation where impeller surfaces would not suffer erosion. Pumps operating with S = 8,000 and even lower are found to suffer from cavitation erosion. Stainless steel impellers can be employed to minimize damage, but if wear is to be avoided for 50 years of operation, then conservative values of S (more submergence) should be considered. A value of S = 7,000 is tentatively recommended and has been used in making submergence calculations. If model tests (with visual inspection for cavitation) indicate a higher value of S is acceptable, then the change should be made in the final plant specification."

In Volume I, Chapter 5, page 5 of the DMJM report the criterion for cavitation is explained as follows:

> "The cavitation criteria for the Tehachapi pump station pumps is minimum damage over the life of the system. However, the importance of efficiency in the economic picture means that the pump design must be optimized for efficiency rather than for minimum submergence. Then, necessary submergence to prevent cavitation damage is to be designed into the plant."

This criterion should be followed very carefully.

DMJM further states:

> "Since some existing pumps do suffer from cavitation erosion at S values of 7900, DMJM feels that design work preliminary to completion of model cavitation tests should be more conservative and should utilize an S value of 7000. NPSH values and pump elevations based on this value are given in Table 9-I. The model tests and studies of material resistance to cavitation erosion will permit final specification of pump cavitation requirements."

The model tests show cavitation at the preliminary recommendation of DMJM of a suction specific speed of 7,000. The submergence recommended in Section VI hereof is based on a suction specific speed of nearly 6,300 at which point the test showed the inception of cavitation.

Another point disclosed by the tests is that the comparative testing of models must be carefully specified. DMJM lists the preliminary model and prototype efficiencies obtained by the pump tests in table 9-11 on page 7 of Chapter 9 in Volume I. The preliminary model efficiency in some cases is the hydraulic efficiency with mechanical losses subtracted. In other cases it is the overall efficiency including the mechanical losses. Further in the text relating to the table, the following is stated on page 6:

> "The testing was performed at speeds lower than required by model test contracts for final tests and in the case of Byron Jackson, the testing was done on a commercial set-up and not on the required final set-up."

Thus, the speed in which a model is tested must be given consideration in the evaluation of the test data.

DMJM further states:

> "The Sulzer model does not have as good a surface finish as the other models have."

This indicates that surface finish has an effect upon the results and may vary from one model to another.

Professor Lawrence C. Neale states the following on page 2 of a report dated April 1965 on the model pump test program for the Tehachapi Crossing, National Engineering Laboratory, East Kilbride, Scotland:

> "The test results on five of these models completed indicate that the efficiency at "best efficiency point" (b.e.p.) as determined at NEL is in agreement within 0.5% of the manufacturers' furnished data."

All of these comments point out that comparative testing of model pumps, whether designed to similar standards or produced by the manufacturers to be competitive in a laboratory, must be made in a common independent laboratory for accurate determination of different efficiencies of various models.

The model tests to date indicate that the two-stage, double-flow pump is significantly more efficient than the four-stage pump.

It should be noted that most of the multistage models which have been built and tested by manufacturers have been two-stage, single-flow pumps which are virtually the same as two-stage, double-flow pumps except for a slight loss due to disc friction in the second stage of the two-stage, single-flow pump, whereas the characteristics of a full four-stage model had not been studied in the laboratory until the Department initiated its research and development program.

The testing programs presently in progress should be continued to obtain as much information as possible on the pump characteristics and upon the effect of variations in designs and in operating conditions. Furthermore, as much information as possible should be obtained by further study of existing pump installations and of the difficulties encountered in the operation and maintenance of such pumps.

11. Bidding notes - Since the value of 1 percent of efficiency is estimated to be in excess of 4 million dollars, the value of 1 percent of efficiency is at least one-third of the cost of the pumps; therefore, in comparing costs, the evaluation of efficiency will most probably be the controlling cost figure. Model pumps submitted by the bidders should be tested before a contract is awarded in order to verify guaranteed efficiencies.

Furthermore, the practice in Europe is to allow a tolerance of plus or minus two percent on field tests. This could result in the acceptance of a pump with an efficiency two percent lower than that predicted or guaranteed if the field test were actually correct and the two percent minus tolerance were claimed by the manufacturer. It does not appear advisable to depend entirely upon field tests for final performance acceptance.

The specifications requesting bids on the pumps for Tehachapi should specify a minimum acceptable efficiency not less than that obtained in the model testing program now being conducted on a two-stage, double-flow pump. Each bidder, if considered as a potential contractor, should be required to submit a model of a particular size and finish for which the bidder should be paid, unless a contract is executed with the bidder for fabrication of the prototype pumps.

B. Valves

1. Types of valves considered - In Volume II, Chapter 5 of the DMJM report there is a review of the study made on valves to date. Section C on page 5-2 describes the valve functions and types. Sliding gate, sluice valves, butterfly valves, needle valves, and rotary valves are listed as the types of valves applicable to most pumping plant isolation functions. A description of each type of valve is given in that section.

Rotary valves are divided into three subdivisions: Cylindrical, cone, or spherical, depending on the shape of the plug which is the rotating part. DMJM states the following on page 3 of said chapter:

> "Design considerations are mainly those of operating head, valve diameter and ease of installation. The opinions given here on relative merits of all valve types except the sliding gate are opinions offered by manufacturers."

> "Intake valves for all lift concept pumping pools are subject to low head and must seal draft tubes of rather large diameter. The sliding gate is commonly utilized in the pumping pool or wherever the sealing interfaces allow easy installation. This includes the concrete surge tank structures at intermediate lift points where penstocks and storage tanks may be isolated by sliding gates."

> "In the case of intakes to the individual pumps at intermediate lift points where no pool is afforded, butterfly, sluice or needle valves might be used."

A specific recommendation is not given on the type of valves to be used in that chapter; however, in Volume I, Chapter 6, the single-lift concept is described, and on page 30 the design and operation of the valves are discussed. DMJM states the following:

> "Three general types of valves can be considered for the single-lift concept pump discharge valve. These are the spherical valve, the needle valve, and the cone plug valve. Sufficient precedent exists for the application of any of these three valve types for the Tehachapi single-lift scheme."

On page 32, DMJM states further:

> "Modern spherical valves are entirely suited to the application and are the least expensive type. Therefore, only spherical valves are further considered for the Tehachapi crossing."

The successful operation of a valve is dependent upon design and fabrication details more than upon the selection of a type of a valve.

2. Selection of valves - The selection of a spherica[l] valve on the basis that it is the least expensive does not insure that a reliable valve will be obtained. In some instances spherical valves which have been used as discharge valves have leaked a sufficient quantity of water to interfere with the starting operations and with repairs. Several manufacturers have developed reliable spherical valves; however, care must be exercised in the writing of specifications and in the qualification of bidders to insure the purchase of reliable spherical valves.

Conical plug valves have had failures because of the body distorting and the plug being locked in a position where it could not rotate because the ribbing on the valve has not been sufficiently strong to prevent excessive deflection from unbalanced pressure on the two sides of the plug. Nevertheless, conical plug valves of proper design have given excellent service in the District's system and elsewhere.

The needle valve has an excellent experience record on high head installations; however, a loss through a needle valve is substantially higher than that through a conical plug valve or spherical valve and the additional loss of head must be considered as a loss of efficiency on the system; therefore, its use is not recommended.

Before a type of discharge valve is selected, a specification must be prepared and thoroughly checked with manufacturers and with engineers in charge of plants where similar valves are installed to insure that bidding will be restricted to those manufacturers who will furnish valves of proven reliability. A valve manufacturing company must then demonstrate that it has produced such valves in sufficient quantity to insure proven reliability in order to be qualified to bid. If such a procedure is followed there would be little choice between a conical plug valve and a spherical valve with movable seats.

On the suction side, slide gates and butterfly valves are considered. Slide gates have a history of good operation under certain conditions. Damage has been incurred by slide gates due to vibration under turbulent flow and by graphitization of cast iron slides. The sealing of slide gates against leakage in the closed position has not been adequate in some instances.

Butterfly valves are constructed of two main types, one with a rubber seat and one with a metal seat. The metal seat has been used for many years and at higher heads than that of the rubber seat which has generally been limited to operation under 125 pounds. The rubber seat has a tighter seal and generally in the last 10 years has proven to be more satisfactory for installations where repeated operations are required. Metal seated butterfly valves have a tendency to seize in the closed position making it difficult to open. If not sealed tightly excessive leakage occurs under repeated operations.

The choice should be made between the slide gates and rubber seated butterfly valves with the rubber seated butterfly valves being favored. Here again a carefully prepared specification is necessary to insure that adequately constructed and reliable valves will be obtained from a qualified manufacturer.

3. Experience - The discharge valve on a two-lift system is required to operate against a head of a thousand feet. The experience record in Europe of large size valves operating against a head of 1000 feet is extensive, whereas the experience record of spherical valves operating against a head of 2000 feet is limited. In the second report on European practice by Professor Hans Gerber and Dr. Robert A. Sutherland, dated January 1965, a discussion of valves for pumping plants is given on page 35. The following is stated:

> "Two main types of valves have found general acceptance in large European pump installations, namely the needle or ring valve (Ringschieber) and the spherical valve (Kugelschieber). The needle valve has been made in a variety of forms, sometimes of the double type, with a closure at both ends. The spherical valve has gradually achieved preeminence for discharge closure, due to its greater simplicity and lower cost, and to its negligible head loss when open. Early spherical valves were not adapted to open or close under load, but such a mode of operation is now quite standard, even at full reverse speed of a pump."

Further, the following is stated in reference to repairs:

> "The service seat of a spherical valve is on the pump side, but in many installations an additional seat is provided on the penstock side and when this is

closed repairs can be made to the service seat. A few installations were seen where two valves were installed in tandem, although this is frequent in high head turbine installations. In such a case the service valve can be removed entirely for overhaul and a sleeve inserted in its place, thus enabling the pump to be restored to service in a short time."

"We recommend for the Tehachapi installation that, as a minimum, auxiliary seats should be provided to enable the service seats to be maintained, and that the use of two valves in series should be considered for a two lift solution and should be definitely adopted for the one lift solution."

"Valve manufacturers have stated that they can make spherical valves for any pump that can be made, and this is borne out by Figure 14, which shows the maximum diameter for various heads so far attained."

"An important accessory to the main discharge valve is the bypass valve which provides adequate circulation to prevent heating of the pump under shut-off conditions."

Figure 14 is included in the report and shows spherical valves operating up to heads of 1,500 meters or 5,000 feet. Valves up to 8 feet in diameter have been used to operate at heads of nearly 900 feet.

4. Two discharge valves in series - It is the District's recommendation that two discharge valves be installed in series on each pump. The reason for this recommendation is to

allow a valve to be taken out of service for repairs of any part, not just the seat as may be done with a spherical valve having an emergency seat on the downstream side. Recently, a bearing on a conical plug valve on the discharge side of one of the District's pumps wore to a diameter such that it was not possible to close the valve completely without having balanced pressures on the two sides of the valve. To repair this valve it was necessary to take three pumps out of service since three pumps were connected to one delivery line.

In the Tehachapi system only two delivery lines will be constructed; therefore, it will be necessary to take out half of the plant in the event of a failure of a discharge valve. Such a failure may occur at a time when it is important to maintain full aqueduct flow as was the case in the repair of the discharge valve on the District's system.

Thus, for dependability two discharge valves are recommended on each pump. Gerber and Sutherland recommend that two valves in series be adopted for the single-lift system and that two valves in series should be considered on a two-lift system.

C. Mechanical controls

Equipment will be required to control the operation of the motor, pump, discharge valve, suction valve, and all auxiliaries. In addition, equipment must be provided to monitor temperatures, water flows, and oil supply, and to initiate control circuits to correct any operation outside of preset limits or to shut down a unit to avoid damage. Such control equipment is essential to good operation of any pumping unit of substantial horsepower rating regardless of its head or flow rating.

1. Number of controls - The same controls are required for pumping units at the first plant of the Tehachapi lift as at the second plant and the number of mechanical controls is a direct function of the number of units to be operated. In a two-lift system 8 pumps in each plant are to be installed ultimately, making a total of 16 pumps for which control equipment must be supplied and maintained to pump water over the Tehachapi. In a single-lift system 14 pumps should be installed ultimately, 13 units to pump the full flow of the canal

plus one spare unit. On a pumping unit basis, control equipment in the ratio of 16 to 14 is required for a two-lift system as compared to that in a single-lift system.

2. Reliability of controls - Control equipment for inlet and discharge valves and for auxiliary equipment on pumping units have been thoroughly developed for reliable operation. Many pumped storage projects in Europe are operated from a control room some distance from the plant and nearly all of the others are operated from a central control room where the operator is isolated from the pumping units.

   In those plants inspected where the control systems were not properly engineered and quality control equipment was not used, there was a period during initial operation when changes and improvements were necessary to obtain dependable automatic operation of the control equipment.

   In other plants, no difficulty was encountered in the control equipment even during the initial periods of operation.

   In order to obtain a reliable and dependable control system, it is necessary to properly design the system using the best control components available, to insist upon good quality workmanship during assembly and installation, and to thoroughly test the system before placing the pumping units in operation.

3. Forebay and reservoir controls - In a two-lift system water level monitoring equipment must be installed in the off-line reservoir in addition to the monitoring equipment installed in the forebay to the first plant. Spare or redundant monitoring equipment should be installed to provide dependable and reliable monitoring of high water levels and low water levels at both plants. In the event that a low water level is reached which would impair the operation of the pumps, the units should be shut down by the initiation of an emergency shutdown sequence from a signal transmitted by the water level monitors. In such an emergency, the difference between a two-lift and a single-lift is only in the number of water level monitoring devices. Each unit would require an emergency tripping sequence control system regardless of its location and since the total number of units is 16 for a

two-lift system and 14 for a single-lift system, the number of such control circuits is virtually the same.

4. Maintenance - Maintenance is required on all control systems; however, it is only necessary to establish a routine maintenance program to keep all systems in proper operation. With one spare unit in each plant over and above that required to pump the full conveyance capacity, such a program can be developed and followed without interference with the delivery of water.
5. Comparison of controls for two-lift and single-lift systems - Controls on a two-lift system exceed those on a single-lift system by only those on two pumping units and on one reservoir monitoring water levels.
6. Flow and pressure measurements - An accurately designed and calibrated venturi tube meter or similar device should be installed on the suction side of each pump so that the amount of water being pumped by each unit can be accurately measured. Such measurement is important to check the performance of the pumping units under various operating conditions

and to indicate any change in performance due to wear. Recordings should be made of the water flow, suction head, discharge head, and power input to the motor for reference purposes.

7. Water hammer control - Water hammer control should be obtained by computing the water hammer with various types of valve operation under emergency conditions of unit shutdown. The timing of the valve should be selected to give the least rise in pressure possible. In all probability it will be necessary to operate the valve at two different rates of speed for emergency closure. The first rate would be faster than the second. An adequate determination of the pressure rise due to the propogation of water hammer pressure waves can be made to design discharge lines, valves, and pump casings.

8. Surge control - Surge control between the forebay and the pumping plant where the distance is appreciable must be obtained by the use of surge tanks at the pumping plant or by the use of a very large conduit between the forebay and plant to substantially reduce the velocity.

9. Control of flow to Tehachapi - The control of the flow of water to the Tehachapi pumping system presents more of a challenge to the designer and operator than the controls of pumping units and the sensing of water levels. The forebay at the bottom of the lift receives water from the canal as it is pumped out of the Wheeler Ridge No. 2 plant, less that water delivered through service connections between Wheeler Ridge and Tehachapi. Storage in addition to that in the forebay is available in the canal by controlling the opening of gates installed in reaches of the canal to regulate the flow of water in each section of the reach between gates. Any excess of water pumped at Wheeler Ridge over that pumped at Tehachapi will increase the water level one or more sections of the canal behind a control gate, assuming that the exact amount of water required for pumping at Tehachapi will be delivered to the forebay. Some latitude in the control of the flow is available because of the storage provided in the forebay. However, this storage is very limited and adjustments must be made frequently to control water levels in the forebay if there is not a balanced flow.

When the water level in the canal adjacent to the Wheeler Ridge plant reaches a high point it will be necessary to adjust the discharge of the pumps at Wheeler Ridge. In the meantime the flow of water to Tehachapi, if carefully controlled, will provide a uniform flow to the pumps enabling them to operate at a uniform rate of discharge. If the pumps at Tehachapi pump more water than is being delivered through the canal the water level in the forebay would be lowered in which case the operator would either observe or be notified by an alarm that the forebay level was being lowered and would request an adjustment in the rate of flow to the Tehachapi plant from a dispatcher controlling water in the aqueduct, or the operator at Tehachapi would be forced to shut down a pump when the water level reached the minimum acceptable point. In the event the operator did not shut down the unit the automatic control circuit would trip a unit off at the low water point set for such tripping.

It should be pointed out that the aqueduct dispatcher could have knowledge of the water level in the forebay if this information is transmitted back to his control center. In such a case the dispatcher could observe the water levels in the forebay, in the various reaches of the canals, and at Wheeler Ridge; could check the flow of water through the Wheeler Ridge plant, at the diversion points between Wheeler Ridge and Tehachapi, and through the Tehachapi pumping units; and could make adjustments at all points as necessary to maintain a uniform flow. Further, it is conceivable that the information would be fed into a computer which would be programmed to make a determination of the adjustments required and in turn would transmit a signal to control systems which would initiate operation of equipment to adjust the flows to a balanced condition.

This control of the flow would be a far more complex control problem than will be experienced in the control of the starting and stopping of pumping units and the balancing of flows in the two pumping plants at the Tehachapi Crossing.

10. Control of flow on a two-lift system - The automatic balancing of flow is inherent in the two-lift system at Tehachapi because a difference in output of the pumps at the two plants will result in a change in the water level in the reservoir at the second plant and as the water level changes the net total pumping head on one plant increases and decreases on the other. This change in total head on the pumps causes a change in the output of the pumps in accordance with the head-capacity curve until a balance is reached in the discharge of the pumps at the two plants. As an example, assume that the lower plant is pumping 5 percent more water than the upper plant at the time the units are started. If seven pumps are in operation at both plants the 5 percent difference in output would mean that the lower plant would be pumping 205 cubic feet per second more than the upper plant and the average difference per pumping unit would be 1/7 of 205 or 29.2 cfs. If the pumps installed in the two plants are so constructed that the head-capacity curves of all pumps are identical with each other, this difference in

flow would be the result of a low water level in the off-line reservoir.

Curve 1 in the Appendix shows a portion of a representative head capacity curve for a two-stage, double-flow pump for Tehachapi. To obtain this curve, all available test data and the predicted curves furnished by pump manufacturers experienced in the fabrication of two-stage, double-flow pumps were adjusted to the same head and flow conditions at the peak efficiency point, then the head-capacity curves from each set of data were plotted on one sheet of cross-section paper for comparison. The shape and slope of the resulting curves were so nearly identical that the representative curve shown in the Appendix was readily determined.

Plotted on the curve are the operating points represented by a difference in flow of 5 percent between the two plants. The total (net) dynamic head on the lower plant would be 963 feet and on the upper plant 1013 feet. The resulting water surface in the off-line reservoir, considering friction losses in the discharge line would be 2179 feet. After placing the two plants in operation the quantity of water pumped by the lower plant would be in excess of that pumped by the upper plant and thereby the amount of water in storage in the off-line reservoir would increase and raise the water level. As the water level increased the total net head on the pumps in the two plants would change tending to equalize the flow in the two plants. The head on the lower plant would increase and the head on the upper plant would decrease. A balanced flow would be reached with a water level in the reservoir of 2204 feet, at which level the head on the pumps in the two plants would be equal at 988 feet, considering friction loss. A schematic diagram in the Appendix shows the elevations of the pumps and the maximum and minimum water levels in the forebay and off-line reservoir.

With only one unit operating in each plant the water level would balance at Elevation 2194.5 feet in the reservoir which is lower because of the difference in friction loss in the two lifts and the resultant decrease in total head in each lift. This condition is shown on Curve II of the Appendix.

A third condition might be experienced wherein the pumping units at the lower plant would deliver 5 percent more water at the design head than those in the second plant at the design head. With seven units operating in each plant, the water level would balance in the forebay at Elevation 2229 as shown on Curve III. If the difference in flow is reversed so that the upper plant would pump more water, the reservoir water level would stabilize at Elevation 2179 feet as shown on Curve IV. Impellers can be trimmed in the pumps after field testing to balance the flow between pumps if desired; however, trimming would not be necessary as is demonstrated herein.

A fourth condition which might be encountered is to operate one pump at the lower plant which will pump 5 percent more at the design head than the pump operating at the second plant. Curve V shows that balanced flow would be reached at Elevation 2222.5. Curve VI shows similar conditions with the pumps installed in the opposite plants. Balanced flow would be reached at Elevation 2167.

All of the water levels at both unbalanced and balanced flow conditions in each of the examples cited herein are within the range of water levels specified in Section VI.

11. Bypass line around discharge valve - To provide circulation of water in the pump during the period of time when the pump is operating against a closed discharge valve, a bypass is necessary which will allow water to be pumped into the discharge line around the discharge valve. A check valve or similar automatic valve should be installed in the line which will open to permit circulation of water and will close to prevent the flow of water from the discharge line back through the pump when the pump is shut down.

X. ELECTRICAL FEATURES

A. Motors

1. General description - A horizontal synchronous motor operating at 600 rpm and directly connected to each pump would be used for the two-lift system. Other characteristics of the motor must be determined by further study. Among the recommendations given in Volume 1, Chapter 2, page 7 of the DMJM report is the following:

> "As soon as the prototype pump type and size has been established a more exhaustive investigation of the driving motors, their starting characteristics and controls should be initiated. As outlined in Chapter 4 of Volume II, there are serious differences of opinion regarding the most desirable starting methods between major motor manufacturers. Therefore, additional studies, including possibly some experimental work, are suggested before this matter can be satisfactorily resolved. The possibility of alternate starting methods to across-the-line starting should be further explored."

2. Motor starting problems - Further studies of the motor starting problem may result in the determination that motors can be built for the Tehachapi pump-lift system which will be self-starting. However, the reliability and the life of such motors cannot be determined readily by such studies. It appears that certain physical problems are involved in the construction of the self-starting motors of

the size and speed required for the Tehachapi pump-lift system. As these problems are resolved for the initial installation of motors it will not be known whether there will be a sufficient margin of safety in the design to insure reliable operation. If it is not necessary to have the motor self-starting, reliable motors of the size required for operation of pumps can be built by any of the major American manufacturers.

3. Alternative methods of starting - There are alternative methods of starting the motors to that of across-the-line full voltage starting. Such methods include (1) connecting the motor with a generator that is either operating at a very low speed or is stopped, then bringing the speed of the generator and motor up together until the motor can be synchronized with the transmission line; (2) providing an electric starting motor to bring the unit up to speed with the pump casing dewatered before energizing the main motor; and (3) starting each unit with a direct-connected turbine which will bring the unit up to speed utilizing water in the delivery line. After the motor is brought up to speed and synchronized, the water in the turbine would be

drained out so that only the windage loss of the impeller would be incurred by the pumping unit as a result of having the turbine direct connected. To obtain reliability in the motors for the Tehachapi pump-lift system, self-starting should not be adopted even if it is determined to be feasible. A separate generator, separate starting motor, or a turbine attached to the shaft should be employed to start the motors. The cost of switchgear for reduced voltage starting and the maintenance of the switchgear is expensive. Across-the-line starting will require a heavy inrush of starting current from the transmission system supplying power to the pumping units. Such an inrush should be avoided if possible. If across-the-line starting is used, serious consideration should be given to reducing the discharge capacity of each pump to reduce the power input requirements to levels at which reliable motors can be used. The number of units installed would be increased to provide a plant output of 4,100 cfs with one unit in reserve.

DMJM states the following in Chapter 2, page 15, Volume II:

"The vast majority of the European installations, 19 out of a total of 27, were arranged for starting by the main turbine on the same shaft, or by an auxiliary turbine."

"Of the nine plants under regular operation started electrically, four were of units under 10,000 HP, and none had units of over 30,000 HP. So they are hardly comparable to the 70,000-80,000 units proposed for the Tehachapi two-lift or single-lift systems. Further, of these five plants with units of over 10,000 HP, only one, that of Grimsel, had operated more than 5700 hours, (8 months of full time operation). Grimsel (29,000 HP) during nine years of service had operated some 21,000 hours, a 30% service factor, but had been started only about 40 times per year for a total of approximately 360 times. No electrical troubles were reported."

"Two relatively large plants, those of Cotilia 40,000 HP and Provvidenza No. III, 67,000 HP, were originally arranged for direct reduced voltage starting. Cotilia was started once electrically and then the reduced voltage equipment was dismantled and, thereafter the units were started by the turbines."

"The 67,000 HP unit at Provvidenza, having a reversible pump turbine, was at first started with reduced voltage electrically. However, after approximately 928 hours of operation and 200 starts, the amortisseur windings expanded from heat and the use of this unit as a pump was discontinued. Arrangements are now being made to use synchronous starting on this unit."

Synchronous starting is used by DMJM to denote the connecting of a generator and motor electrically at or near zero speed and increase the speed of both at the same time.

4. Thrust bearings - The two-stage, double-flow pump with a shaft in a horizontal position and directly

connected to the motor also with a shaft in a horizontal position requires no thrust bearing to withstand hydraulic thrust or to support the weight of the rotating parts. The design of the pump provides a balance of the hydraulic thrust and all the weight is supported in a radial direction. Vertically mounted units such as those proposed for a single-lift system for Tehachapi require heavy duty thrust bearings. In Chapter 6, page 34, Volume I, DMJM states as follows:

> "The four-stage pump has a balancing ring for hydraulic thrust control and normally operates with approximately 57 tons total load (hydraulic thrust + weight of rotating parts). At start-up, the load may reach 90 tons, so a thrust bearing in the motor of 100-ton capacity will be needed. Final design will require a check on weights of all rotating parts, as the intermediate shaft length may vary some and the motor rotor weight will be known with greater accuracy."

On page 37 of the same chapter DMJM states further:

> "It is suggested that thrust bearings suffer practically no wear with the possible exception of that which may occur at the instant of starting or stopping when the oil film is thin. Wear is small even under these conditions because of an adsorbed coating of lubricant on the bearing surfaces. It may be that the amount of bearing wear which occurs on start and stop will not be significant over the years of intermittent operation at Tehachapi. If this wear is considered a problem, it presumably may be remedied through the use of high pressure lubrication systems. Again, no proportionate increase in bearing maintenance with number of starts may be seen in field data."

The difficulties of heavy duty thrust bearings are eliminated in the horizontal arrangement of the two-stage, double-flow pumps.

B. Power supply

As shown on plate 18 of the Department's report dated April 1965, two power lines would be brought into the pumping plants on the Tehachapi Crossing. A large substation with disconnecting switches, circuit breakers, and transformers would be required at each of the two pumping plants of a two-lift system. The additional cost of the second substation over the one required for a single-lift system has been taken into consideration in all of the cost estimates prepared to date and the cost of the additional substation is offset by the saving in steel in discharge lines. Suitable sites are available for locating substations at each plant.

The effects of the characteristics of the power system which will supply power to the pumping plants at Tehachapi on the design of the motors should be carefully considered.

C. Control equipment

1. Centralized control room - As stated hereinbefore, a centralized control room would be located in one of the two plants, most probably in the lower plant. All control equipment should be provided in duplicate or triplicate as mentioned

hereinbefore. Likewise, control circuits between plants and within plants should be in duplicate or triplicate to avoid failure of the control system because of a circuit outage. Such control equipment and control systems have been developed to the point where reliability is equal to that of any equipment within the pumping plant. The large electrical network which will supply power to the Tehachapi pumping plants will be operated using equipment controlled by automatic and remote control circuits. Control circuits and equipment for the Tehachapi pumps should be just as reliable as those used in large electric utility systems.

2. Step by step control circuitry - Controls for the Tehachapi pumps should be designed so that it would be necessary for the operator to push only a single button to select and place in operation a pumping unit at either plant. All functions necessary to be performed to place the pumping unit in operation and to protect the equipment during operation should be automatically started and controlled in the starting sequence circuits. Provisions should be made to permit manual initiation of each function of the automatic control system so that the operator may duplicate the operation of the automatic starting operation. In the event of

a failure of the automatic circuit an operator can place a pump on the line or remove a pump from the line from the control room by manually controlling the starting sequence. The operation of each device on an automatic control circuit must be indicated on a control panel so that the operator can observe whether the operation was completed or not. Without such indication it is difficult to locate a device which might not have operated, thereby preventing the automatic operation from being completed. This method of automatic operation with a complete indication on a panel of the response of each device to a control signal is used in many pumping plants, pumped storage plants and hydroelectric plants. The equipment and systems for such automatic operation are fully developed and are reliable.

3. Interlocks - It is customary to provide interlocks on all of the equipment operating within a pumping plant so that the equipment will be in the proper position before the main pumping unit can be started. The interlocks should prevent starting a unit if conditions are such that damage may occur to some equipment. Such interlocking of all the equipment should

be provided on the pumping units at the Tehachapi plant.

4. Control circuits - With proper controls and interlocks, the two plants at the Tehachapi Crossing can be operated from a remote control center as is done at Vianden and at other pumped storage projects and hydroelectric installations.

5. Automatic circuits - Automatic starting and stopping sequences on the pumping plants can and should be designed to (1) prevent starting a unit if the water level in the forebay or intermediate reservoir is too low; (2) open the suction valve before a unit is started; (3) start operation of water systems to coolers and oil systems to bearings; (4) check flow of water and oil to determine that such systems are in operation before the unit is started; (5) trip a unit in event of stoppage of oil flow; (6) shut down water and oil systems when a unit is shut down; (7) depress water in the pump casing during starting; (8) open the discharge valve after the motor is synchronized and close said valve during shutdown; (9) start a unit in the second plant in the proper sequence after a unit is

started at the first plant; (10) shut down a unit at the second plant when a unit is shut down at the first plant; and (11) perform other functions necessary to safeguard the operation of the pumping system.

6. Maintenance - Any type of control system requires routine maintenance if reliable and dependable operation is to be expected. With a complete spare pumping unit over and above the number required to pump the full design flow of the conveyance facilities to and from Tehachapi, a program can be developed to regularly check and maintain the control system on each unit when it is the standby unit in the rotation of units for operating service.

XI. COSTS

On page 6 of the letter, dated May 8, 1965, to Mr. Golze', the Tehachapi Crossing Consulting Board stated that ". . ., the Board concludes that estimated costs of construction and operation have been shown to have minimum influence on the choice of scheme." The conclusion reached is reasonable based on the reports of estimated costs. However, consideration should be given to two points, efficiency and possible variations of actual costs from estimated costs.

1. Efficiency - Most of the cost comparisons have used efficiencies for a four-stage pump and a single-lift system approximately 1 percent below that of two-stage, double-flow pumps for a two-lift system. The tests on the model pumps show a 2-1/2 percent difference in efficiency between the units in favor of a two-stage, double-flow pump. In Table III-2 of the Department's report dated April 19, 1965, the total head loss for a two-lift system on the ridge is shown to be 65.2 feet while the total head loss for a single-lift system on the ridge is shown as 72.2 feet with underground discharge lines and 63.5 feet with surface discharge lines. Since the head loss of a two-lift system is virtually equal

to or less than that for a single-lift system, the cost of power for operating the pumping plants is substantially less year by year for a two-lift system than for a single-lift system because of the 2-1/2 percent better efficiency of the two-stage, double-flow pump. Whereas it is necessary for comparison with capital costs to reduce this annual cost of power to present worth for comparison of capital costs, the annual cost should be considered separately to appreciate the effect of the higher efficiency of the two-stage, double-flow pumps.

2. Actual cost versus estimated cost - The actual cost of the single-lift system may be subject to more of a deviation from the estimated cost than the two-lift system because of the influence on initial bids or the cost of extra work orders resulting from additional difficulty which will be encountered in the fabrication and welding of either the thicker steel plate or the special steels required for the higher pressure delivery line. Furthermore, the cost of fabricating four-stage pumps cannot be determined as accurately because such pumps have not been built in the size required for Tehachapi. Pumps equal to and larger than those required for a two-lift system have been built.

XII. DEPENDABILITY AND RELIABILITY

For the Tehachapi Crossing a dependable and reliable pumping system cannot be assured merely by the selection of a type of system. Dependability and reliability must be built into a system by selecting appropriate design criteria, by the rigorous application of engineering analysis in designing the system and each component, in the preparation of detailed specifications for equipment based on the results of survey of existing installations, and by thorough inspection to control the quality of each component during fabrication and construction of the system.

It is also necessary to make provisions in the designs for the complete maintenance and overhaul of the equipment. Spare units must be installed to permit routine maintenance, redundant control circuits must be provided so that the mode of operation determined to be the best by actual experience may be adopted without modification of the circuits, and sufficient duplication of auxiliary equipment should be available to permit operation of a unit when a small piece of equipment is out of service.

1. Reliability of components - In defining the scope of the reliability study, DMJM stresses the importance of component design, material selection, maintenance, and spares planning in Volume II, Chapter 7, page 1 as follows:

"The scope of the reliability study is restricted to pumps and pump components as major considerations with accessory equipment such as motors, valves, bearings, and so forth receiving minor attention. It is also limited to Tehachapi operations as isolated from those of upstream and downstream plants. However, detailed technical analysis of the pumps as they affect reliability and availability will yield the most valid predictions for the lift concepts since pump maintenance is singularly amenable to accurate weighting and prognostication. It follows that pump component design and material selection as guided by results of this study will do more to enhance operational success at Tehachapi than any other planning function. It is also apparent that maintenance and spares planning will be most effective if its most accurately predictable facets receive greatest stress."

Reliability does not depend upon the pumps alone. Records of pumping plants in operation will indicate that all the components have an effect on the reliability and the study should be expanded to include all equipment.

2. Numerical reliability - In Volume I, Chapter 9, page 3, DMJM gives a numerical rating of comparative reliability to one-, two-, and three-lift systems using the term "concept effectiveness" to describe the product of operational reliability and operational availability. The ratings are given as follows:

Pump Concept	Concept Effectiveness
Single-lift	97.9%
Two-lift	95.0%
Three-lift	90.2%

In Volume II, Chapter 7, page 81, DMJM comments on the validity of the lift concept effectiveness as follows:

> "The validity of lift concept effectiveness as a comparative index does not appear to be subject to dispute at this time. Neither the reliability nor the availability of individual pumps designed for about the same head per stage, capacity and speed varies enough to be a factor whether the pumps be one, two, or four stage. Where the one lift concept is inherently more reliable than the other two is in the fact that it requires only one system to operate successfully while the others demand success of two out of two or three out of three. If the chances of one system succeeding are x, the chances of three systems succeeding are x^3, because the chances of having a failure are greater."

Since DMJM states that neither the reliability nor the availability is a factor whether the pumps be one-, two-, or four-stage, the operation concept effectiveness of the Colorado River Aqueduct in which five pumping plants are operated in series should be considered as an example to test the validity of the relative ratings derived for the three systems considered for Tehachapi. The pumps in the Colorado River Aqueduct are single-stage pumps.

3. Reliability of Colorado River Aqueduct - DMJM states that "If the chances of one system succeeding are x, the chances of three systems succeeding are x^3, because the chances of having a failure are greater." The Colorado River Aqueduct has five systems, that is five pumping plants in series. Using the apparent rate of decay in concept effectiveness with the increase in the number of systems or plants in series as is shown by DMJM in the comparison of one-, two-, and three-lift systems, the Colorado River Aqueduct would have a concept effectiveness of less than 82 percent. Yet operational records on the Colorado River Aqueduct show a much higher concept effectiveness. In fact, the occasions on which the system is not available to pump the quantity of water required is very rare, less than once a year.

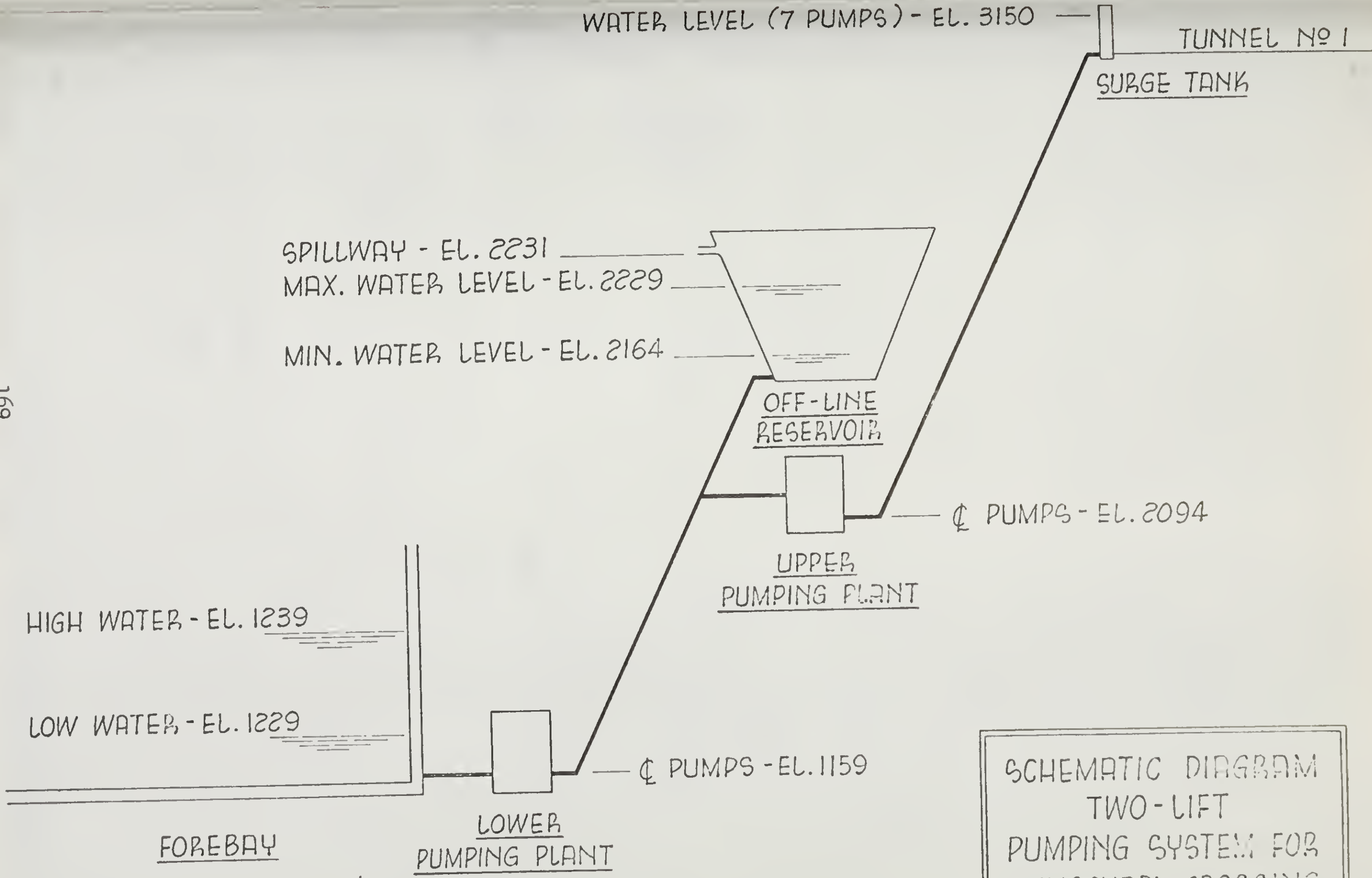
4. Reliability of California Aqueduct - In the California Aqueduct there would be eight pumping plants, considering a two-lift system at Tehachapi, operating in series which deliver water to Castaic reservoir. The

concept effectiveness of such a system might be computed to be less than 70 percent using the rate of decay of concept effectiveness shown by DMJM for the one-, two-, and three-lift systems at Tehachapi. The California Aqueduct must be more reliable and dependable than 70 percent, and it is evident that the Department of Water Resources is making every effort to design a system of much higher reliability and dependability and will succeed in building such a system.

5. Reliability of other systems - Rather complete records have been kept on the three pumped storage plants in a system near the Rhine in Germany, Schluchseewerk A.G. The availability and reliability expressed in percent has been in excess of 99 percent. Reliability factors below 99 percent could not be tolerated on most pumping systems inspected in Europe and the United States.

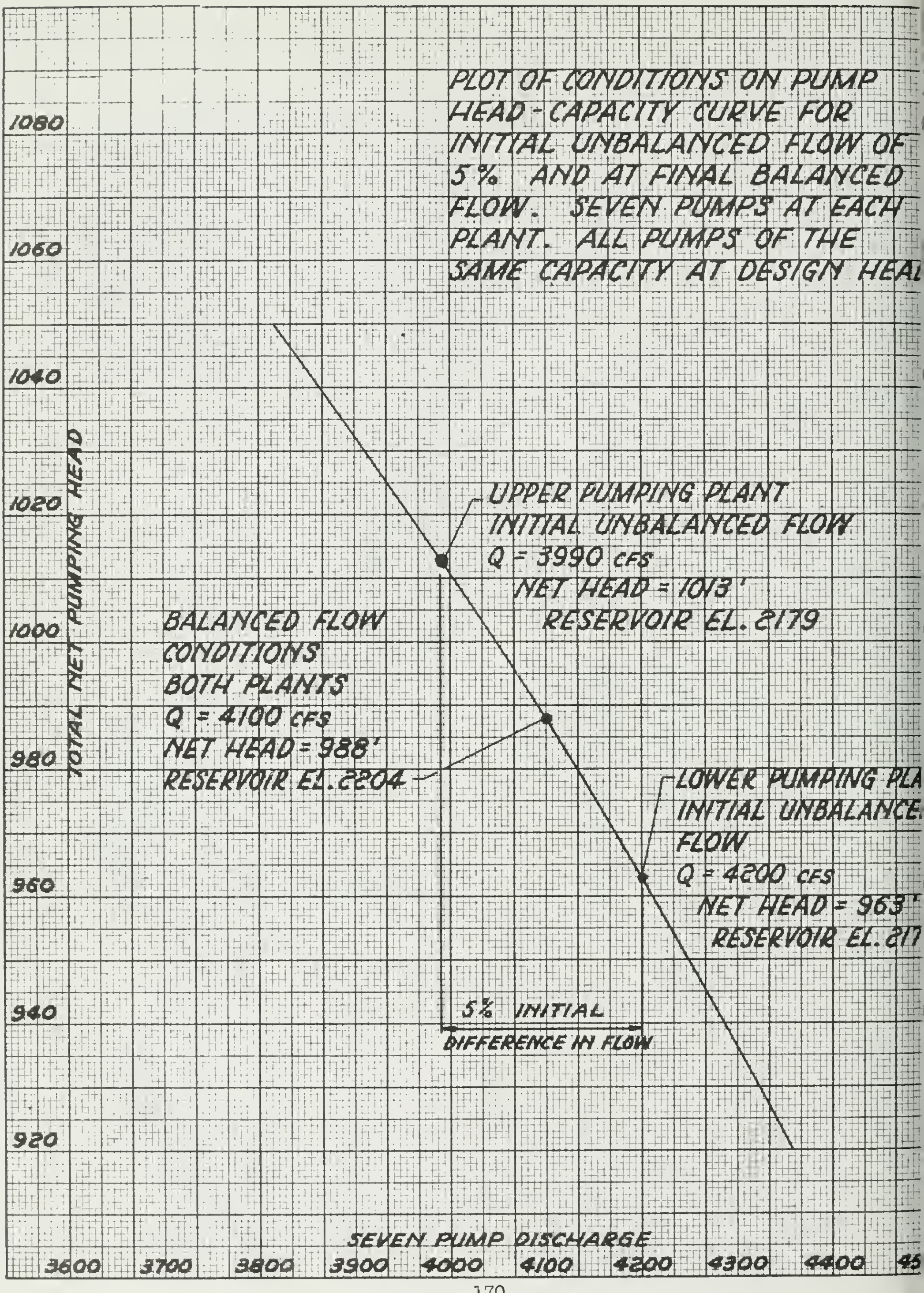
6. Expected reliability - By paying proper attention to the design and construction of all components and by a very careful control of quality of all components, the reliability and dependability of the Tehachapi pumping system can be very high. If expressed as percentage, it should exceed 99 percent regardless of the type of system selected.

XIII. APPENDIX

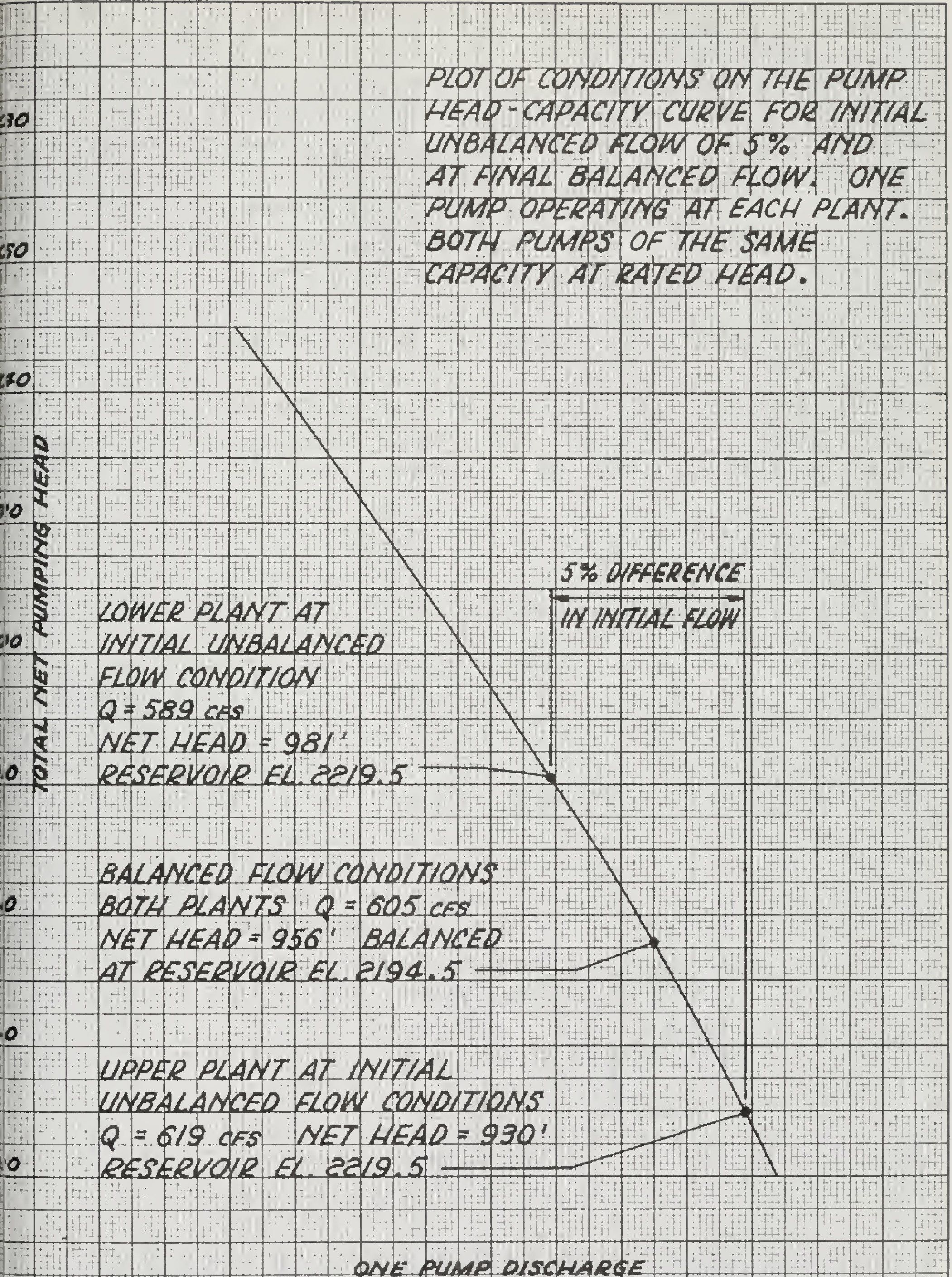


SCHEMATIC DIAGRAM
TWO-LIFT
PUMPING SYSTEM FOR
TEHACHAPI CROSSING

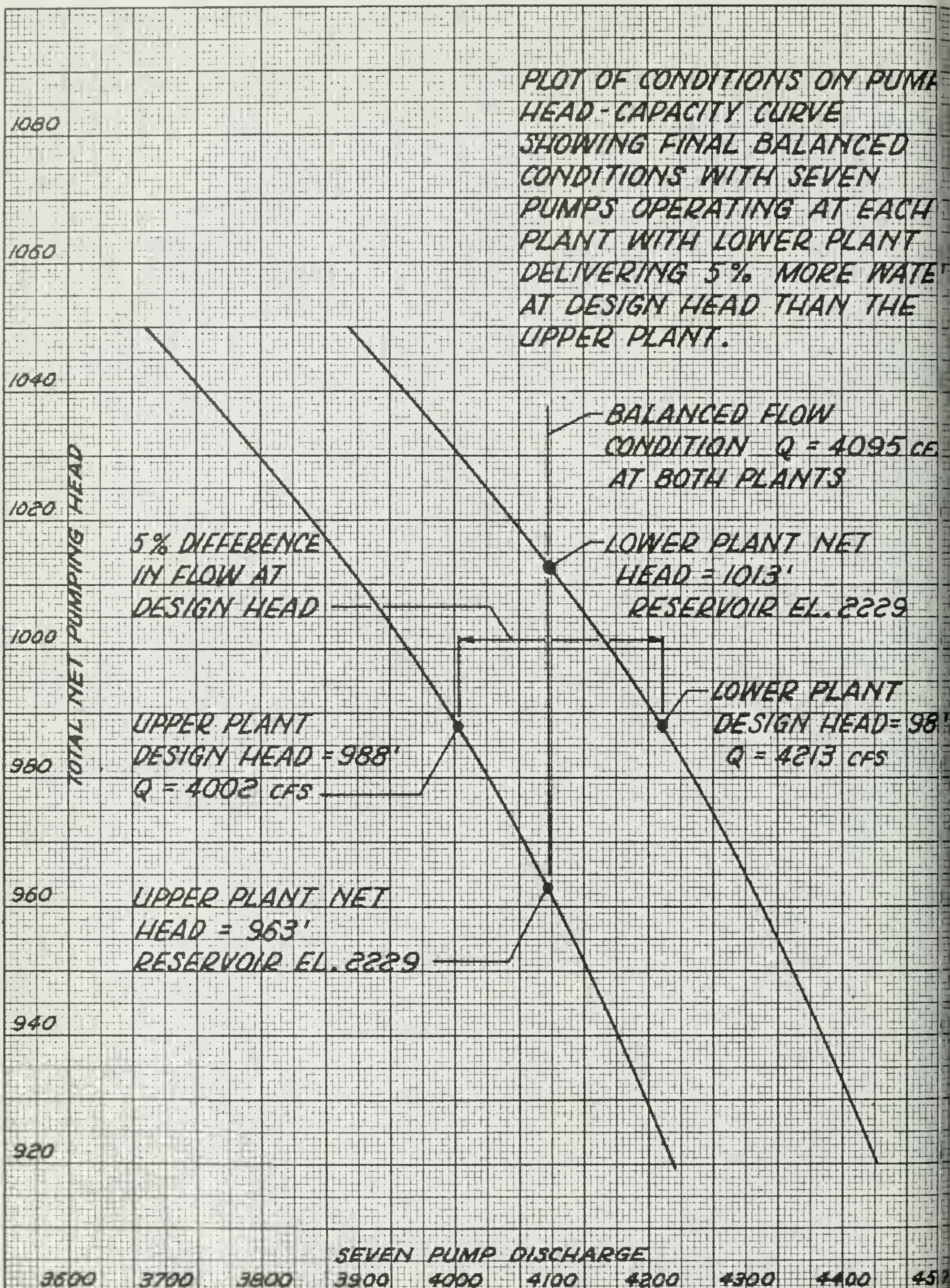
CURVE I


PLOT OF CONDITIONS ON PUMP HEAD - CAPACITY CURVE FOR INITIAL UNBALANCED FLOW OF 5% AND AT FINAL BALANCED FLOW. SEVEN PUMPS AT EACH PLANT. ALL PUMPS OF THE SAME CAPACITY AT DESIGN HEA
UPPER PUMPING PLANT INITIAL UNBALANCED FLOW Q = 3990 CFS NET HEAD = 1013' RESERVOIR EL. 2179
BALANCED FLOW CONDITIONS BOTH PLANTS Q = 4100 CFS NET HEAD = 988' RESERVOIR EL. 2204
LOWER PUMPING PLA INITIAL UNBALANCE FLOW Q = 4200 CFS NET HEAD = 963' RESERVOIR EL. 217
5% INITIAL DIFFERENCE IN FLOW
TOTAL NET PUMPING HEAD
SEVEN PUMP DISCHARGE
1080
1060
1040
1020
1000
980
960
940
920
3600
3700
3800
3900
4000
4100
4200
4300
4400
45

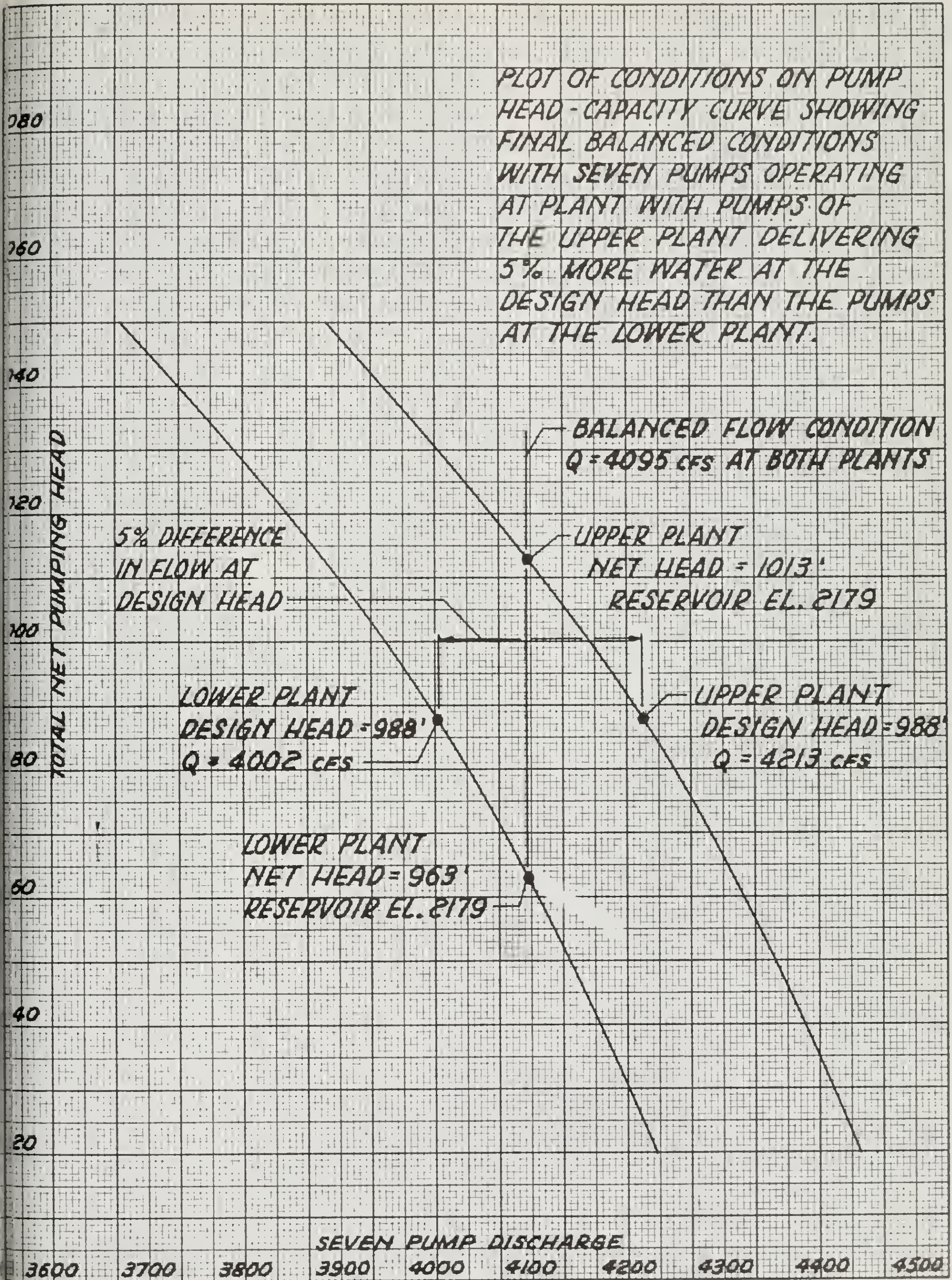
CURVE II

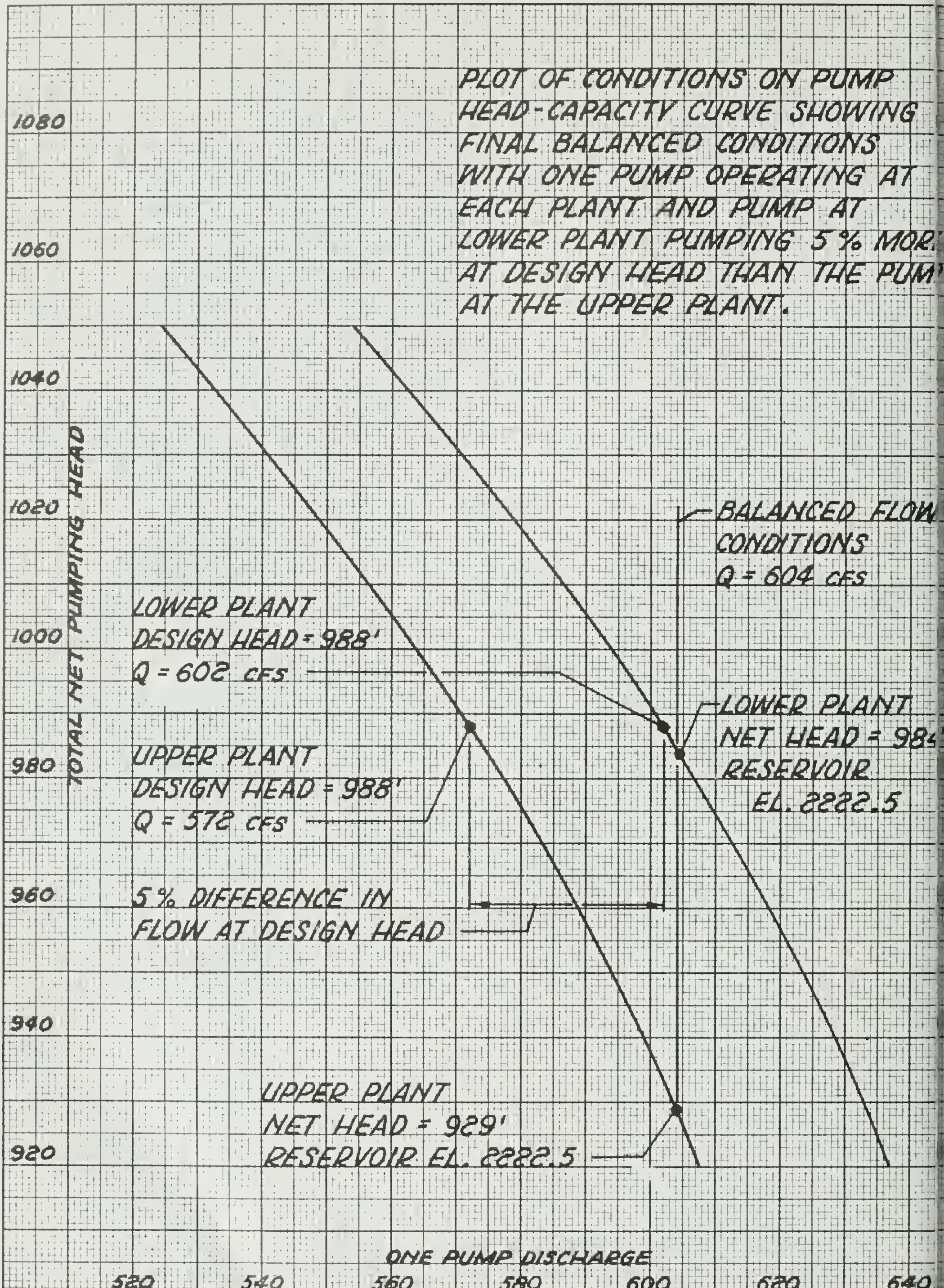

PLOT OF CONDITIONS ON THE PUMP HEAD-CAPACITY CURVE FOR INITIAL UNBALANCED FLOW OF 5% AND AT FINAL BALANCED FLOW. ONE PUMP OPERATING AT EACH PLANT. BOTH PUMPS OF THE SAME CAPACITY AT RATED HEAD.
5% DIFFERENCE IN INITIAL FLOW
LOWER PLANT AT INITIAL UNBALANCED FLOW CONDITION Q = 589 CFS NET HEAD = 981' RESERVOIR EL. 2219.5
BALANCED FLOW CONDITIONS BOTH PLANTS Q = 605 CFS NET HEAD = 956' BALANCED AT RESERVOIR EL. 2194.5
UPPER PLANT AT INITIAL UNBALANCED FLOW CONDITIONS Q = 619 CFS NET HEAD = 930' RESERVOIR EL. 2219.5
TOTAL NET PUMPING HEAD
ONE PUMP DISCHARGE
520
540
560
580
600
620
640

CURVE III

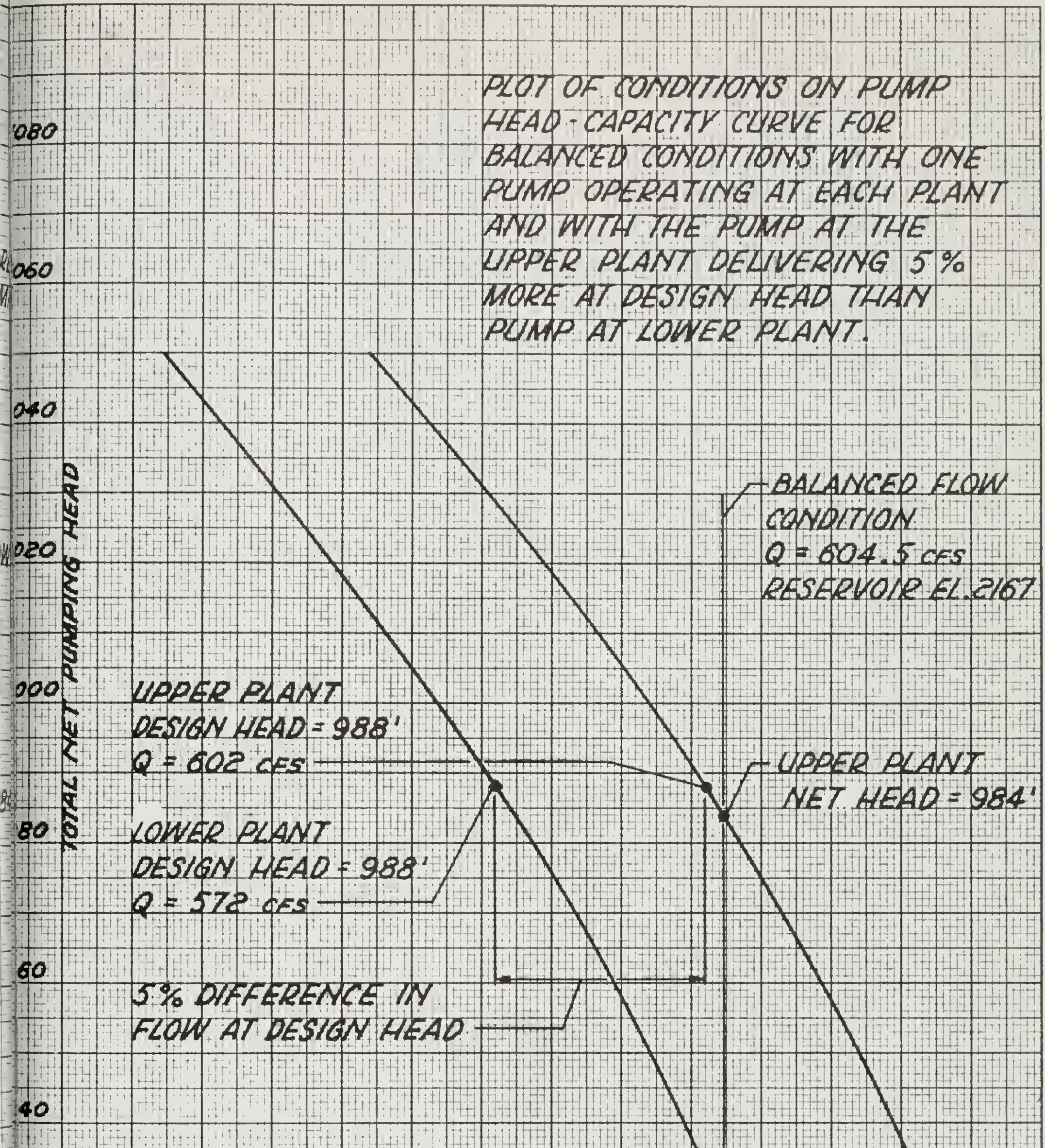


PLOT OF CONDITIONS ON PUMP HEAD-CAPACITY CURVE SHOWING FINAL BALANCED CONDITIONS WITH SEVEN PUMPS OPERATING AT EACH PLANT WITH LOWER PLANT DELIVERING 5% MORE WATER AT DESIGN HEAD THAN THE UPPER PLANT.
BALANCED FLOW CONDITION Q = 4095 CFS AT BOTH PLANTS
LOWER PLANT NET HEAD = 1013' RESERVOIR EL. 2229
5% DIFFERENCE IN FLOW AT DESIGN HEAD
LOWER PLANT DESIGN HEAD = 98
Q = 4213 CFS
UPPER PLANT DESIGN HEAD = 988'
Q = 4002 CFS
UPPER PLANT NET HEAD = 963' RESERVOIR EL. 2229
TOTAL NET PUMPING HEAD
1080
1060
1040
1020
1000
980
960
940
920
SEVEN PUMP DISCHARGE
3600
3700
3800
3900
4000
4100
4200
4300
4400
45


PLOT OF CONDITIONS ON PUMP HEAD-CAPACITY CURVE SHOWING FINAL BALANCED CONDITIONS WITH SEVEN PUMPS OPERATING AT PLANT WITH PUMPS OF THE UPPER PLANT DELIVERING 5% MORE WATER AT THE DESIGN HEAD THAN THE PUMPS AT THE LOWER PLANT.
BALANCED FLOW CONDITION
Q = 4095 CFS AT BOTH PLANTS
UPPER PLANT
NET HEAD = 1013'
RESERVOIR EL. 2179
5% DIFFERENCE
IN FLOW AT
DESIGN HEAD
LOWER PLANT
DESIGN HEAD = 988'
Q = 4002 CFS
UPPER PLANT
DESIGN HEAD = 988'
Q = 4213 CFS
LOWER PLANT
NET HEAD = 963'
RESERVOIR EL. 2179
TOTAL NET PUMPING HEAD
080
060
040
020
000
80
60
40
20
SEVEN PUMP DISCHARGE
3600
3700
3800
3900
4000
4100
4200
4300
4400
4500


PLOT OF CONDITIONS ON PUMP HEAD-CAPACITY CURVE SHOWING FINAL BALANCED CONDITIONS WITH ONE PUMP OPERATING AT EACH PLANT AND PUMP AT LOWER PLANT PUMPING 5% MOR[E] AT DESIGN HEAD THAN THE PUM[P] AT THE UPPER PLANT.
TOTAL NET PUMPING HEAD
1080
1060
1040
1020
1000
980
960
940
920
BALANCED FLOW CONDITIONS Q = 604 CFS
LOWER PLANT DESIGN HEAD = 988' Q = 602 CFS
LOWER PLANT NET HEAD = 98[4] RESERVOIR EL. 2222.5
UPPER PLANT DESIGN HEAD = 988' Q = 572 CFS
5% DIFFERENCE IN FLOW AT DESIGN HEAD
UPPER PLANT NET HEAD = 929' RESERVOIR EL. 2222.5
ONE PUMP DISCHARGE
520
540
560
580
600
620
640

CURVE VI


PLOT OF CONDITIONS ON PUMP HEAD - CAPACITY CURVE FOR BALANCED CONDITIONS WITH ONE PUMP OPERATING AT EACH PLANT AND WITH THE PUMP AT THE UPPER PLANT DELIVERING 5 % MORE AT DESIGN HEAD THAN PUMP AT LOWER PLANT.
BALANCED FLOW CONDITION
Q = 604.5 CFS
RESERVOIR EL. 2167
UPPER PLANT
DESIGN HEAD = 988'
Q = 602 CFS
UPPER PLANT
NET HEAD = 984'
LOWER PLANT
DESIGN HEAD = 988'
Q = 572 CFS
5% DIFFERENCE IN FLOW AT DESIGN HEAD
LOWER PLANT
NET HEAD = 928'
TOTAL NET PUMPING HEAD
1080
1060
1040
1020
1000
980
960
940
920
ONE PUMP DISCHARGE
520
540
560
580
600
620
640

Report on

RIDGE LOCATION PUMP SYSTEMS
SINGLE-LIFT AND TWO-LIFT

for the

TEHACHAPI CROSSING

of the

CALIFORNIA STATE WATER PROJECT

for

THE METROPOLITAN WATER DISTRICT OF SOUTHERN CALIFORNIA

Prepared By

BECHTEL CORPORATION

SAN FRANCISCO

JULY 1965

Issued July 16, 1965

BECHTEL CORPORATION
ENGINEERS-CONSTRUCTORS
TWO TWENTY BUSH STREET . . . . SAN FRANCISCO, CALIF. 94119

July 7, 1965

Mr. R.A. Skinner
General Manager & Chief Engineer
Metropolitan Water District
of Southern California
P.O. Box 54153, Terminal Annex
Los Angeles 54, California

Subject: <u>Tehachapi Pump-Lift</u>

Dear Mr. Skinner:

The attached report develops and compares three alternative single-lift and two-lift systems along the ridge location at Tehachapi, each having twin underground discharge lines. The two two-lift systems utilize the same intermediate reservoir, with alternative locations for Pumping Plant No. 2. Four-stage, single-suction, vertical pumps are used in the single-lift system and two-stage, double-suction, horizontal pumps are proposed for the two-lift systems. Alternative consideration of single-stage pumps is proposed if this type can be demonstrated to be superior before the pumps must be ordered.

On the basis of all of Bechtel's investigations to date, as reported or referred to in the report, Bechtel's principal recommendation is that, on the basis of present development, a two-lift system utilizing two-stage, double-flow, horizontal pumps should be adopted. The preferable location for Pumping Plant No. 2 is on the nose of the flat ridge adjacent to the dam of the intermediate reservoir. An urgent program to determine whether two-stage, double-flow pumps or single-stage pumps are superior is recommended. Other important recommendations also are presented.

The report contains supporting statements and comments from each of Bechtel's five outstanding consultants, who have devoted major amounts of time and thought to this important subject.

BECHTEL CORPORATION

Mr. R.A. Skinner
Metropolitan Water District of
Southern California
Los Angeles 54, California

July 7, 1965

It is hoped that this report will be of value in selecting the best pump-lift system and in suggesting important design criteria and the most suitable general types of structures. Bechtel stands ready to amplify and support the recommendations in more detail if desired and to be of further assistance in attaining the best design for this most important unit of the California Aqueduct.

Very truly yours,

John P. Buehler

John P. Buehler
Vice President and Manager
of Hydro Department

JPB/ds
Encl.

CALIFORNIA STATE WATER PROJECT
TEHACHAPI CROSSING
RIDGE LOCATION PUMP SYSTEMS
SINGLE-LIFT AND TWO-LIFT

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DRAWINGS

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CHAPTER I

INTRODUCTION

The Bechtel "Second Interim Report on Alternative Schemes for the Tehachapi Crossing", dated January 1965, and the supplement thereto, dated April 1965, developed and compared several arrangements of single-lift, two-lift and three-lift pump systems on locations along the ridge, in Pastoria Creek, and combinations thereof. Subsequent to submission of the January 1965 report, additional geological explorations by both DWR and Bechtel were directed primarily to possible structure locations in Pastoria Creek and to the possible off-line intermediate reservoir of a two-equal-lift system along the ridge.

The recent explorations at the site of the intermediate reservoir of the Pastoria Creek two-lift system disclosed some unanticipated deficiencies which would substantially increase the cost of this key element of the pump system previously considered by Bechtel to be the most favorable. Furthermore, in April 1965, the DWR Consulting Board for Earthquake Analysis expressed a preference for systems along the ridge location as being less vulnerable to damage and presenting less potential hazards to life and property than systems located in the canyon. This Board also expressed concern over the possible location of a dam and reservoir in the vicinity of the Garlock fault, which is the site of the upper reservoir for all two-lift and three-lift systems in Pastoria Creek

Bechtel does not consider that the geological deficiencies disclosed are sufficient to render the Pastoria Creek locations infeasible. However, it is recognized that the measures required to provide fully safe structures would increase the cost to such extent that systems utilizing Pastoria Creek no longer would have a substantial economic attraction in comparison with systems along the ridge. Furthermore, Bechtel recognizes that in evaluating the complex geological conditions and seismic hazards, there are many indeterminate factors upon which the judgment of highly qualified experts might not agree. Much more detailed geological investigations would be required to establish the feasibility of Pastoria Creek sites. Time does not permit these additional explorations.

In view of these circumstances, Bechtel recommended to the Tehachapi Crossing Consulting Board on May 5, 1965, that it would not be prudent to adopt a system utilizing Pastoria Creek for the present project.

Consequently, in this report, only the ridge location is considered. Furthermore, since favorable sites have not been located along the ridge for the two intermediate reservoirs required for an attractive three-lift system, consideration herein is given only to the single-lift system and to two alternative arrangements of a two-equal-lift system utilizing the same off-line intermediate reservoir. Current geological explorations, now almost complete, indicate this site to be quite favorable.

Previous Bechtel reports were based upon a total pumping capacity of 5000 cfs to provide an annual average flow of 4650 cfs, as then considered by DWR. In its April 1965 report, the DWR defines the pumping requirements as a maximum capacity of 4093 cfs. This capacity, therefore, has been adopted as the basis of design herein. However, in the arrangements developed herein, the number and size of the pumps has been selected to provide one complete spare pump in each pumping plant. Bechtel considers this to be a sound and necessary provision to allow adequate time for outage during maintenance and overhaul in a realistic program of operation for this important unit of the California Aqueduct.

Both the Consulting Board for Earthquake Analysis and the Tehachapi Crossing Consulting Board have expressed the opinion that underground discharge lines would be subject to less hazard of disruption from seismic shocks than would surface pipes supported on the weathered material of the steep slopes. Bechtel concurs in this opinion and, therefore, utilizes underground discharge lines throughout in the systems considered in this report. Underground discharge lines for a two-lift system are fully as practicable as for a single-lift system, in which the profile rises in two steps in any case.

Previous Bechtel studies and those in the DWR report of April 1965 have shown only small differences in estimated capital and operating costs for the more favorable pump-lift systems. Furthermore, Bechtel considers, and has recommended in the past, that reliability is far more important than cost in selection of the pump-lift system. The Tehachapi Crossing Consulting Board concurred in this view in their report of May 8, 1965. Therefore, although both capital and operating costs are estimated for the systems presented herein, these costs should have a minimum influence on the selection of the system. Dependability and reliability of operation and ease of maintenance must be the controlling factors.

The two-lift systems developed herein utilize two-stage, double-flow, horizontal pumps with split casings. This is the only pump of the types considered for either of the lift systems which has been fully proven by long-term satisfactory operation under conditions of head, capacity and specific speed that bracket the Tehachapi requirements in all respects. Four-stage, single-flow, vertical pumps are utilized for the single-lift system. Alternative pumping plant layouts are presented utilizing single-stage, single-suction, vertical pumps for the two-lift systems. Although both of these latter two types of pumps require further development, there is some possibility that one or both can be developed successfully for their respective applicable uses at Tehachapi. Other arrangements of the pumping plants also are presented to indicate some of the alternative design possibilities.

It is not intended that the arrangements shown, nor the specific details, such as the size of the discharge lines and the number and capacity of the pumps, should be considered as definite recommendations for final design. The preliminary designs shown are presented principally to provide a valid basis for comparison of the pump-lift systems. While it is believed that these arrangements and details have some merit, they should be analyzed in more detail in final design of the selected system.

This report utilizes the principal applicable information presented in the previous Bechtel reports of September 1964, January 1965 and April 1965, and that presented by Bechtel and its consultants in statements to the Tehachapi Crossing Consulting Board on May 5, 1965. This information is not repeated herein but is considered to be incorporated by reference in the bibliography to support the statements, evaluations and conclusions presented. Some additional information developed subsequently and applicable to the systems considered also is presented. In addition, Appendix B includes letters from the Bechtel Consultants giving their comments on the report dated May 8, 1965 of the Tehachapi Crossing Consulting Board; Appendix C includes letters from these same consultants expressing their concurrence in the general conclusions of this report and authorizing use of their names; and, finally, Appendix D includes telegrams from the four American and three European manufacturers expressing their views concerning alternative types of pumps in response to Bechtel's telegraphic inquiry of May 21, 1965.

CHAPTER II

GEOLOGY AND SEISMOLOGY

DWR EVALUATION

The following geologic description and evaluation is extracted from the DWR "Report on Alternative Locations of Tehachapi Lift System", dated April 1965.

Forebay. - Excavation will be mostly in alluvium composed extensively of silty sand. Cut slopes are recommended to be 2:1 with berms.

The forebay dike is located on 0 to 60 feet of alluvial materials which overlie fractured basalt which will require extensive grouting to prevent leakage.

Station A Pumping Plant. - (This plant is at the same location as Bechtel Pumping Plants No. 1.)
The pumping plant is founded entirely on the Tejon formation. This formation dips 30 to 35 degrees to the northwest and consists of firm sandstone having minor interbeds of siltstone. Overlying alluvium ranges in depth from 5 to 65 feet. Static water is about 20 feet below ground surface and dewatering is not expected to offer unusual problems. Excavation of the sandstones will be done by ripping and possibly light blasting. Cut slopes should be stable at 1.5:1 with berms except at the

southern portion where the beds dip into the excavation where slopes of 2:1 will be required for stability. It is indicated that the sandstone has adequate strength to support the proposed structure. A fault crosses the foundation area, and two other faults are suspected. A slight shift in the plant location may be required to avoid the weak materials associated with the faults.

Discharge Lines. - (Discharge lines for all systems presented herein are underground. Although the alignment of the lines is different for each system, the geological features described below are applicable to all lines.) The discharge lines are located in gneissic diorite which is a hard and strong rock with an average fracture spacing of 4 feet. Foliation and banding are generally well developed and trend roughly parallel to the discharge lines alignment. The foliation usually dips steeply to the east. Folding is difficult to define, but it is indicated in several places that tight isoclinal folding is an important feature of the rock structure.

The area is traversed in a northeast direction by several shear zones. They are from 2 to 10 feet wide and are composed of sheared, decomposed to highly fractured rock affected by mineralization and chemical alteration. A few thin clay gouge seams are also evident.

Maximum known depth of weathered rock is 95 feet but the average depth along the discharge lines is 10 feet.

The major portions of the discharge lines will be located below the ground water surface.

Results of rock tests indicate that the gneissic diorite is competent and suitable as a foundation material for the discharge lines.

Off-Line Dam Site. - (Bechtel's dam site as considered in this report is at the DWR axis). The dam is located in a V-shaped canyon with an extremely steep gradient. The foundation rock is moderately to deeply weathered gneissic diorite which is cut by many pegmatite veins from two to five feet wide. The entire dam site area is mantled by soil which has widespread evidence of shallow creep.

At the time of preparation of the DWR April 1965 report the dam site exploration consisted of two trenches and three drill holes. Two additional holes and an investigation of potential borrow areas were in progress.

The site appears to be well suited for an earth and rock dam. No serious construction problems are anticipated. The site may be adequate for construction of a concrete structure; however, additional drill hole information is needed to verify the feasibility of a concrete dam.

Right Abutment. - This abutment slopes fairly uniformly at about 25 degrees. There are very few outcrops above the stream channel and these consist primarily of pegmatite dikes. No major zones of weakness have been found. DDH-89 drilled into the abutment on a 60 degree angle penetrated moderately to deeply weathered gneissic diorite to a depth of 45 feet. Generally, there is a noticeable improvement in the rock condition at 24 feet.

The rock condition changes abruptly at 45 feet. Below this depth the rock is fresh and hard and rust staining is confined to isolated, prominent fractures. Water test results reflect this rock condition also.

Preparation of foundation for a fill dam, 167 feet high are:

1. Strip 25 feet under impervious core.
2. Remove 15 feet under rockfill and gravel section.

Left Abutment. - This abutment has a steep slope which averages 33 degrees and has no outcrops. There is a soil mantle which is 5 to 10 feet deep and which is underlain by decomposed, friable, gneissic diorite. No major shearing or crushing was observed. Foundation rock is expected to improve below 25 to 30 feet. It is estimated that foundation preparation will include:

1. Strip 30 feet under impervious core.

2. Strip 20 feet under rockfill and gravel sections.

Station B Pumping Plant. - (This plant is at the same location as Bechtel Pumping Plant No. 2 on Ridge. DWR does not have a pumping plant site comparable to Bechtel Pumping Plant No. 2 at dam.) As of April 1965, exploration consisted of 2 trenches and 1 access road. It was planned to diamond drill two additional holes, make a geophysical study and perform rock tests.

The foundation will be strong, hard, fractured gneissic diorite. No unusual construction problems are anticipated. At least 4 minor faults in the area have been exposed. They are from 2 to 3 feet wide. The cut will be almost entirely in hard, weathered gneissic diorite and will be stable on a 1:1 slope with berms.

BECHTEL EVALUATION

Since the DWR report was issued, additional field explorations have been and are being made. Bechtel has kept in touch with these by actual inspection and through discussions with the DWR geologists. The Bechtel evaluation of the geologic conditions is presented in the following paragraphs.

Pumping Plant No. 1 - The pumping plant envisioned by Bechtel would require a deeper excavation and the plant would be oriented differently from that planned by DWR. This deeper excavation would place the lower part of the cut in hard, competent diorite rock rather than the less competent Tejon formation. Bechtel used an average slope of 1.5:1 for all four of the cut slopes.

The orientation proposed by Bechtel is subject to less extensive landslides. This opinion is based on the fact the sediments dip to the north about 30 to 35 degrees and hence the southern side of the excavation is expected to be less stable than the other sides. The DWR plan has a much longer cut along this southern side and hence has more area of slide exposure. Final recommendations on the pumping plant location, orientation and cut slopes cannot be made until the exploration program is completed; however, available data indicates that the Bechtel plan is well adapted to site conditions.

Off-Line Dam Site. - The dam site considered in this report is at the DWR axis, but the crest elevation used by Bechtel is about 12 feet higher than that shown by DWR. Bedrock in the area is hard, relatively fresh dioritic gneiss. On the basis of recent explorations, Bechtel considers the foundation to be competent for either a concrete or a fill dam.

Major slides in this area are unlikely, even considering that earthquake shock and saturation of areas surrounding the proposed reservoir may occur. This evaluation is based on the fact that the soil cover in the area is quite shallow, generally less than 10 feet, and hence deep seated slides are unlikely.

Soil creep is probable in the area because of its extent and the steep slopes. However, potential soil creep can be controlled by the use of interceptor channels which would prevent the debris from entering the reservoir or by some other of the numerous methods of slope stabilization.

Moderately to highly weathered rock generally extends from 10 to 30 feet below the soil cover.

There are no geologic conditions which would seriously affect the reservoir in this area. Although there are zones of weaker material deep in the right abutment, foundation conditions for a properly designed and constructed dam or pumping plant are suitable.

It is estimated that the foundation treatment may require 10 to 15 feet stripping for a fill type dam and 30 to 40 feet for a gravity dam.

Pumping Plants No. 2. - The DWR pumping plant site and Bechtel's ridge site are in the same general location. The

DWR site requires a permanently exposed cut of about 190 feet height which would yield about 1.5 million cubic yards of excavation. Bechtel's plant located near the dam will require an exposed cut of only some 80 feet height and 0.5 million cubic yards of excavation.

The foundation rock at both sites is hard, moderately massive to highly jointed dioritic gneiss. Although several minor faults have been found in the area, both sites offer competent foundations. Excavation in this hard rock should be quite stable.

CHAPTER III

PUMP-LIFT SYSTEMS CONSIDERED

SINGLE-LIFT SYSTEM

This arrangement is similar to Scheme VII of Bechtel's "First Interim Report" and closely similar to DWR System No.5 as described in the DWR, April 1965 Report. The forebay is located identically with that of DWR at an area about 5,000 feet easterly from Pastoria Creek. The pumping plant is also at the DWR location but is longitudinally oriented and contains 14 four-stage pumps (315 cfs, 1983 Head, 78,800 HP) thus providing one complete spare over the required total discharge of 4,093 cfs. From this pumping plant two underground discharge pipes rise in a two-step arrangement, similar to that considered by DWR, to a combination gate house and surge tank at the portal of DWR Tunnel No. 1. An alternation of three tunnels and three siphons connects this surge tank to the inlet portal of Carley V. Porter Tunnel of the Tehachapi Crossing.

This arrangement is shown in Plan and Profile on Plate 1.

TWO-LIFT SYSTEM WITH PUMPING PLANT NO. 2 ON RIDGE

This arrangement is a two-equal-lift system, with intermediate reservoir located similar to DWR system No. 4 as described in the DWR April 1965 Report. The forebay and intake channel are identical to those used by DWR. Pumping Plant No. 1 is a longitudinal-discharge layout utilizing 8 two-stage, double-flow, horizontal pumps (585 cfs, 992' Head, 72,400 HP) thus providing one complete spare. Pumping Plant No. 2 is similar to Pumping Plant No. 1 except that it is an above-ground arrangement with all discharge from the same side of the plant. From Pumping Plant No. 1, two underground discharge pipes rise to Pumping Plant No. 2. The surge chamber at the top of this lift is located along an off-line tunnel leading to the intermediate reservoir and is a shaft entirely in rock.

The intermediate reservoir is at the DWR location with an earth-and-rock dam having its crest at about Elevation 2245. Debris dam protection is provided with a bypass channel separated from the reservoir spillway. This channel also intercepts any slope wash from the hillsides east of the reservoir site. A ditch is also provided on the west side of the reservoir to perform a similar function.

From Pumping Plant No. 2, two underground discharge tunnels rise to the same combination gate house and surge tank, and the same sequence of three tunnels and three siphons, as is used for all ridge route schemes.

This arrangement is shown in Plan and Profile on Plate 2.

TWO-LIFT SYSTEM WITH PUMPING PLANT NO. 2 AT DAM

This arrangement is similar to the two-lift system previously described and utilizes the same forebay, intake channel, Pumping Plant No. 1 and off-line, intermediate reservoir. Pumping Plant No. 2, however, is located a short distance downstream from the dam on a flat ridge. This location renders it free of danger from slides.

Both discharge lines are underground with the discharge from Pumping Plant No. 2 all on one side. No surge chamber is required at the top of the first lift due to the proximity of the reservoir.

The same combination gate house and surge tank and the same sequence of three tunnels and three siphons is used as was used with the previous systems.

This arrangement is shown in Plan and Profile on Plate 3.

A tabulation of the "Principal Engineering Data" for these three systems is presented on the following page.

PRINCIPAL ENGINEERING DATA

System	Single Lift	Two Lift with P.P. #2 on Ridge	Two Lift with P.P. # at Dam
Number of Lifts	1	2-Equal	2-Equal
Route	Ridge	Ridge	Ridge
Design Discharge	4,093	4,093	4,093
Canal Normal Water Surface Elevation; feet	1,239	1,239	1,239
Forebay			
Maximum Operating Water Surface Elevation; feet	1,239	1,239	1,239
Normal Operating Water Surface Elevation; feet	1,234	1,234	1,234
Minimum Operating Water Surface Elevation; feet	1,229	1,229	1,229
Area at Normal Water Surface Elevation; acres	35	35	35
Storage for Shutdown; minutes at design discharge	30	30	30
Storage for Start-up; minutes at design discharge	30	30	30
Useful Operating Storage; acre-feet	340	340	340
Pumping Plant No. 1			
Number of Units	14	8	8
Capacity per Unit; cfs	315	585	585
Rated Head; feet	1,983	992	994
Type of Pump	4S,SS-V	2S,DS-H	2S,DS-H
Elevation of ℄ of Pumps; feet	1,159	1,161	1,161
Horsepower per Unit	78,800	72,400	72,500
N_s Specific Speed	2,150	2,070	2,070
Submergence at Normal Water Surface; feet	80	78	78
Submergence at Minimum Water Surface; feet	70	68	68
Pumping Plant No. 2			
Number of Units	None	8	8
Capacity per Unit; cfs	None	585	585
Rated Head; feet	None	992	994
Type of Pump	None	2S,DS-H	2S,DS-H
Elevation of ℄ of Pumps; feet	None	2,100	2,100
Horsepower per Unit	None	72,400	72,500
N_s Specific Speed	None	2,070	2,070
Submergence at Normal Water Surface; feet	None	110	108
Submergence at Minimum Water Surface; feet	None	68	64
Discharge Lines for Pumping Plant No. 1			
Type	Underground	Underground	Underground
Number of Lines	2	2	2
Inside Diameter; feet	12.5	13.0	13.0
Maximum Steel Thickness; inches	3.22	1.91	1.91
Minimum Steel Thickness; inches	0.57	0.59	0.59
Length; feet	8,470	3,590	4,680

System	Single Lift	Two Lift with P.P. #2 on Ridge	Two Lift with P.P. #2 at Dam
Discharge Lines for Pumping Plant No. 2			
Type	None	Underground	Underground
Number of Lines	None	2	2
Inside Diameter; feet	None	13.0	13.0
Maximum Steel Thickness; inches	None	1.91	1.91
Minimum Steel Thickness; inches	None	0.59	0.59
Length; feet	None	4,620	4,520
Number of Combination Surge Tank and Gate House	1	2	1
Off-line Water Passageways			
Length of Tunnel; feet	None	2,000	None
Length of Pipe in Trench; feet	None	None	700
Intermediate Reservoir			
Maximum Operating Water Surface Elevation; feet	None	2,231	2,230
Normal Operating Water Surface Elevation; feet	None	2,210	2,208
Minimum Operating Water Surface Elevation; feet	None	2,168	2,164
Overflow Spillway Crest Elevation; feet	None	2,231	2,230
Elevation at 4,100 cfs Continuous Overflow; feet	None	2,238	2,237
Elevation of Top of Dam; feet	None	2,245	2,244
Maximum Height of Dam; feet	None	195	195
Length of Dam; feet	None	650	650
Type of Dam	None	Earth & Rock	Earth & Rock
Dam Upstream Slope; H:V	None	2.5:1	2.5:1
Dam Downstream Slope; H:V	None	2.25:1	2.25:1
Spillway Type	None	Side Channel	Side Channel
Spillway Capacity; cfs	None	4,100	4,100
Debris Dam			
Storage Capacity; Cu.Yd.	None	10,000	10,000
By-pass Channel Capacity; cfs	None	2,000	2,000
Elevation of H.G. line at Entrance to Tunnel No. 1 at Design Discharge; feet	3,175	3,175	3,175
Static Lift as Measured between Intake at Pumping Plant #1 and to H.G. Line at Entrance to Tunnel #1 at Design Discharge; feet	1,936	1,936	1,936
Hydraulic Losses at Design Discharge between Intake at Pumping Plant #1 and Entrance to Tunnel #1	47	47	51
Tunnels 1, 2 and 3			
Total Length; feet	16,803	16,803	16,803
Diameter; feet	21.5	21.5	21.5
Siphons 1, 2 and 3			
Total Length; feet	2,593	2,593	2,593

CHAPTER IV

BASIS OF PRELIMINARY DESIGN

Forebay and Canal

Criteria for the design of the forebay remain unchanged from those of the "Second Interim Report" except as affected by the design capacity change from 5,000 cfs to 4,100 cfs. This results in an area change from 42 acres to 35 acres, an inlet crest length reduction from 1,000 feet to 800 feet and a spillway crest length reduction from 400 feet to 330 feet. Accordingly, the forebay used herein has 30 minutes of full-flow storage in a 5-foot depth change; either up, for flow rejection, or down, for flow start-up.

The cost of main canal easterly from a point 350 feet westerly from Pastoria Creek, is included in the estimates.

Pumping Plants

Pumps in the single-lift system analyzed herein are assumed to be four-stage, single-suction vertical centrifugal pumps without alternatives. Pumps in the two-lift systems are assumed to be two-stage, double-suction horizontal pumps, with the possible alternative of single-stage, single-suction vertical pumps. The number of units per pumping plant is tentatively selected as fourteen (315 cfs each) for the single-lift system and eight (585 cfs each) for the two-lift systems. This keeps unit capacities very close to those used for systems in the "Second Interim Report". Although future study may indicate that some other number of units is to be preferred, the cost comparisons will not be affected by such a change.

Pumping plant layouts are still not refined sufficiently for final design, but have been given some additional study. As a result, a plant having two parallel rows of units has been adopted as being appreciably less expensive than the more customary single row of units. Layouts of such plants are shown on Plates No. 5 and 6, in their application to a two-lift forebay location.

No specific provisions have been included on the arrangement drawings for starting the pumps. This important problem needs more detailed consideration to assure selection of the best method. Although the motor capacities are not significantly different for single-lift and two-lift systems, the four-stage pump for a single-lift system presents a much more severe problem, since it has not been considered feasible to date to unwater this pump for start-up. Even if model investigations should indicate this to be feasible, it would not be prudent to rely upon this completely unproven method for such an important installation as Tehachapi.

Two-stage, double-flow, horizontal pumps and single-stage pumps do not present a start-up problem of the same magnitude, since they can be unwatered readily and thus require much less power to get up to speed before introducing the water. In either case, however, whether started full against closed valves, or whether started in air, Bechtel favors a back-to-back arrangement, whereby the pumps and motors are brought up to speed by an electrical connection to a turbine-driven generator. In the case of the four-stage pumps started in water, this would require a turbine-generator unit to have approximately 60 percent of the capacity of the pump motors, while 15 percent of the motor capacity would be entirely adequate for starting unwatered two-stage or single-stage pumps. Costs for such turbine-generator units are included in the cost estimates.

Discharge Pipes.

All discharge pipes considered herein are of the underground type. Pipe diameters were determined by the economic study method outlined in the "Second Interim Report". The revised power rates assumed for this economic study were: \$16.00 per kw capacity plus 2.0 mills per kwh of energy for continuous power; no capacity charge plus 3.0 mills per kwh of energy for off-peak power. Off-peak power was used during the system capacity build-up period only, and then for partial flows only. Base date was revised to January 1, 1965. Pumping plant construction costs and operating costs were considered, as were also differences in discharge pipe costs. As a result, the value per foot of conveyance losses was redetermined to be $212,000.

Pipe manifolds at pumping plants were similarly analyzed for economic sizes, and the costs so determined were included in discharge pipe costs.

The same steels were used as were used for the "Second Interim Report."

<u>Surge Tanks and Control Gates</u>.

The combination gate house and surge tank arrangement used in the "Second Interim Report" was used herein, at the entrance of Tunnel No. 1, without cost change. For the two-lift system with Pumping Plant No. 2 on Ridge, a similar combination was used near Pumping Plant No. 2, but height requirements were such that it was considered necessary to build it as a shaft in rock. At Pumping Plant No. 2, at either location, facilities are provided to admit air and to prevent backflow into first-lift discharge pipes under any emergency condition.

<u>Tunnels 1, 2 and 3</u>

Economic analysis of tunnels indicated that a 20.0 foot inside diameter would be a good selection. The DWR report of April 1965 showed a corresponding diameter of 23.0 feet. It was assumed that the eventual diameter would be somewhat less than 23 feet and, for the purpose of this report, a diameter of 21.5 feet was used.

Siphons

Ridge route siphon designs were not reviewed at this time and costs used in the DWR Report on April 1965 were accepted for use in this report.

Dam

Dam design is of a preliminary nature based upon the most up-to-date geological investigations. It is an earth-and-rock dam, basically sloped 2.5:1 upstream and 2.25:1 downstream. Spillway consists of an ungated side channel and chute which will have a capacity of 4,100 cfs. Reservoir capacity, above and below "normal" water surface is about 30 minutes of 4,100 cfs flow.

Debris Dam

Drainage area is so small that debris dam cost is considered to be nominal. A by-pass channel will prevent storm waters from entering the main reservoir. This channel will start at the debris dam and end downstream from the main dam and will have a capacity in excess of 2,000 cfs.

CHAPTER V

ESTIMATES OF CONSTRUCTION AND OPERATING COSTS

COMPARATIVE CONSTRUCTION COSTS

The estimated comparative construction costs of the three systems considered herein are summarized as follows:

System	Pump Type	Comparative Construction Cost in Millions of Dollars	
		Total	Difference
Single Lift	4S, SS-V	117.3	Base
2-Lift, PP No. 2 on Ridge	2S, DS-H	125.9	+8.6
2-Lift, PP No. 2 at Dam	2S, DS-H	125.5	+8.2

All systems are on the ridge route and use underground discharge pipelines.

As for the "Second Interim Report", the above total estimated comparative construction costs include an allowance of 30% for engineering and contingencies. However, no allowance is included for land costs, for rights-of-way, for escalation or for interest during construction, so these costs are incomplete and are comparable only with each other. These costs are based upon 1965 prices with construction "all at once" for the same reasons as were used for the "Second Interim Report".

The comparative construction costs of the three systems are presented in more detail in the following two tables:

COMPARATIVE CONSTRUCTION COSTS
SUMMARIZED BY PRINCIPAL FEATURES

System	Costs in Millions of Dollars		
	Single-Lift	2-Lift PP No.2 on Ridge	2-Lift PP No.2 at Dam
Pumping Plants	43.2	47.5	46.3
Discharge Pipes	21.4	18.2	20.1
Off-Line Water Passageways	-	1.7	1.4
Dams	-	3.2	3.2
Forebay, Surge Tanks	3.9	4.5	3.9
Tunnels	18.6	18.6	18.6
Siphons	2.6	2.6	2.6
Access Roads	0.5	0.6	0.5
Subtotal	90.2	96.9	96.6
Eng. & Cont. @ 30%	27.1	29.0	28.9
Total Construction Cost	117.3	125.9	125.5

SUMMARY OF ESTIMATED CONSTRUCTION COSTS IN THOUSANDS OF DOLLARS

System	Single-Lift	2-Lift PP No.2 on Ridge	2-Lift PP No.2 at Dam
Pump Type	4S, SS-V	2S, DS-H	2S, DS-H
Forebay	3,053	3,053	3,053
Pumping Plant No. 1	43,271	24,934	25,024
Discharge Pipes	21,457	7,868	10,157
Surge Tank No. 1	800	688	None
Off-Line Water Passageways	None	1,675	1,438
Dam	None	2,684	2,684
Debris Dam	None	525	525
Pumping Plant No. 2	None	22,511	21,177
Discharge Pipes	None	10,356	9,966
Surge Tank No. 2	None	800	800
Tunnels 1, 2 & 3	18,576	18,576	18,576
Siphons 1, 2 & 3	2,620	2,620	2,620
Access Roads	464	583	540
Sub-Total	90,241	96,873	96,560
Eng. & Cont. @ 30%	27,072	29,062	28,968
TOTAL	117,313	125,935	125,528

COMPARATIVE OPERATING COSTS

The estimated comparative annual operating costs, including differences in conveyance losses as well as differences in the efficiencies of different types of pumps, of the three systems considered herein are summarized below:

System	Pump-Type	Comparative Annual Operating Cost in Millions of Dollars: Total	Difference
Single-Lift	4S,SS-V	27.7	Base
2-Lift,PP No.2 on Ridge	2S, DS-H	27.5	-0.2
2-Lift,PP No.2 at Dam	2S, DS-H	27.5	-0.2

The above annual operating costs are based upon the equipment efficiencies used in the "Second Interim Report", despite the fact that examination of recently available results of preliminary tests indicates that the four-stage pump may not attain the efficiency originally expected while the two-stage pump may exceed its assumed efficiency, thus resulting in a difference of at least two percent rather than the one percent used in the cost comparison herein. The original assumptions result in the following overall system pumping efficiencies:

System	Pump Type	Efficiency %
Single-Lift	4S, SS-V	86.5
2-Lift,PP No.2 on Ridge	2S, DS-H	87.4
2-Lift,PP No.2 at Dam	2S, DS-H	87.4

Continuous power cost is based upon a capacity rate of $16.00 per kw per year plus an energy rate of 2.0 mills per kwh. Off-peak power cost is based upon no capacity charge but an energy rate of 3.0 mills per kwh. Power costs are based upon 8,150 hours of operation per year at an average pumping rate of 3,850 cfs. Annual operating costs also include operating, maintenance and replacement charges of:

$3.40 per kw per year for single-lift pumping plant;

$3.45 per kw per year for two-lift pumping plants using two-stage, double-suction pumps;

0.35% of construction cost per year for underground discharge pipes;

0.25% of construction cost per year for all other structures.

All costs are based upon complete installations operating at the full average pumping rate. Off-peak power is used only during the build-up period, and therefore does not enter into the computations of results shown in this table.

Pumping plant operating and maintenance costs are based upon the same assumptions and adjustments as were used for the "Second Interim Report".

The estimated conveyance losses between the canal at the intake of Pumping Plant No. 1 and the entrance to Tunnel No. 1 for the average pumping rate of 3,850 cfs, are as follows:

System	Pump Type	Estimated Conveyance Loss-Feet Total	Difference
Single-Lift	4S, SS-V	42	Base
2-Lift,PP No.2 on Ridge	2S, DS-H	42	0
2-Lift,PP No.2 at Dam	2S, DS-H	45	+3

It should be noted that differences in conveyance losses are small, especially when compared with the total pumping head of some 1,970 feet for the 3850 cfs average pumping rate.

These comparative annual operating costs are presented in more detail on the following page.

ESTIMATED COMPARATIVE ANNUAL OPERATING COSTS

System	Single-Lift	2-Lift PP No.2 on Ridge	2-Lift PP No.2 at Dam
Pump Type	4S, SS-V	2S, DS-H	2S, DS-H
Pumping Plant	1 @ 14 Units	2 @ 8 Units	2 @ 8 Units
System Capacity -cfs	4,100	4,100	4,100
Average Pumping Rate -cfs	3,850	3,850	3,850
Annual Operating Costs in Millions of Dollars			
Pumping Plant, O&M	2.705	2.716	2.722
Other Structures, O&M	0.181	0.184	0.190
Capacity @ $16.00/KW	12.728	12.598	12.623
Energy @ 2.0 Mills/KWH	12.084	11.960	11.985
Total Annual Operating Cost	27.698	27.458	27.520

COMPARATIVE TOTAL COSTS

For the same reasons that were used in the "Second Interim Report", it is considered that differences in construction costs on an "all at once" basis represent the present value of differences in bond payments. By making a trial run for a typical case involving a water build-up period utilizing some off-peak power from 1971 to 1991 and full operation from 1991 through 2040, it has been determined that a factor of 13 is a reasonable value for converting annual operating cost differentials to the appropriate present value. Accordingly, the cost differentials shown above are here combined, using the factor of 13 applied to annual operating cost differentials, to show the present value of the cost differences between the various schemes.

ESTIMATED COMPARATIVE TOTAL COST DIFFERENTIALS

System	Pump Type	Comparative Cost Differentials in Millions of Dollars			
		Constr. Cost	Annual Oper. Cost.	Present Worth of Oper. Cost.	Present Worth of Total Cost
Single-Lift	4S, SS-V	Base	Base	Base	Base
2-Lift, PP No.2 on Ridge	2S, DS-H	+8.6	-0.2	-2.6	+6.0
2-Lift, PP No.2 at Dam	2S, DS-H	+8.2	-0.2	-2.6	+5.6

It should be noted that the above cost differentials are based upon the originally assumed pump efficiencies rather than those indicated by recent preliminary tests. If final tests verify present indications, the differences in present worth of total cost shown above would be virtually eliminated, making the present worth of total costs approximately equal for all systems.

CHAPTER VI

RELATIVE EVALUATION OF ALTERNATIVE SYSTEMS

Each of the three alternative systems presented herein is feasible from an engineering standpoint and is susceptible of development by good engineering design to provide adequate safety against all reasonable hazards. Relatively, however, there are differences in site conditions inherent to each system, differences in vulnerability of the structures and equipment to damage from natural hazards, and differences in the dependability and reliability of operation and the ease of maintenance. Some of these differences can be evaluated at least qualitatively on the basis of established facts, while the evaluation of others of a more intangible nature depends primarily on judgment.

Bechtel's evaluation of the various factors applying to each of the alternative systems is presented in the following discussion. No consideration is given to the intake channel and forebay nor to the gate house, surge chamber, tunnels and siphons beyond the top of the pump-lift, since these structures are common to all systems considered.

ENGINEERING EVALUATION OF GEOLOGY AND SEISMOLOGY

Although the geologic conditions at the different sites affect the suitability of foundations, the stability of slopes etc., it is assumed that the detailed treatment of the engineering problems involved will be such as to provide approximately equal safety against anticipated hazards. Likewise, while the degree of seismic action would be equal at all locations under consideration, the vulnerability of each structure would depend on the particular site conditions, the design requirements, the design treatment and the type and arrangement of the equipment.

Pumping Plants. - The forebay pumping plant of either a single-lift or a two-lift system will be excavated in the Tejon formation consisting of firm sandstone with minor interbeds of siltstone, which is deemed competent for the proposed structures. The DWR recommends cut slopes at $1\frac{1}{2}$:1 and 2:1 with berms. However, a very deep and large excavation is required that will present some potential hazard, principally as regards slope stability under severe earthquakes.

Pumping Plant No. 2 at either of the two alternative sites for a two-lift system will be founded upon hard, strong, fractured gneissic diorite of adequate strength.

The DWR recommends 1 : 1 slopes with berms in this rock. The plant site on the backbone of the ridge requires a deep cut, which could present seismic hazards. The alternative site on the nose of the flat ridge near the dam of the intermediate reservoir requires only minor excavation, with little or no hazard of slides. Both sites for Pumping Plant No. 2 are superior to that for Pumping Plant No. 1.

From a geological and seismic standpoint, the advantage of the single plant of a single-lift system, as compared with the two plants in a two-lift system, is quite small in view of the superior sites available for Pumping Plant No. 2, especially if this plant is located on the nose of the flat ridge near the dam of the intermediate reservoir.

Pumps. - Four-stage, vertical pumps characteristically are supported by a thrust bearing at the bottom and are braced laterally by brackets extending to the concrete walls of the pump pit. Even if thus substantially supported, this imposing, free-standing pump structure of considerable height might be subject to a considerable hazard of dislocation or rupture from a severe seismic shock. Since the pumping plants in Europe are not subject to seismic conditions comparable to Tehachapi, there is no precedent to gage the degree of this hazard. Although it would be possible to encase a major portion of the pump in concrete, this would greatly complicate dismantling for inspection and maintenance.

On the other hand, two-stage, double-flow pumps set horizontally with the discharge pipe extending horizontally from the bottom and encased in mass-concrete, as in the Bechtel suggested design, are much more stable against seismic shock. The center of gravity of the pump is low, the bottom portion of the casing, the two suction pipes and the discharge pipe all are rigidly supported by concrete. These features minimize any hazard of dislocation or rupture.

Likewise, if alternative single-stage pumps were utilized, the mass-concrete encasement of the entire inlet elbow, the pump casing and the discharge pipe would provide great rigidity and safety against seismic hazards.

Consequently the pumps available for a two-lift system are substantially superior to the pumps of a single-lift system as regards susceptibility to seismic damage.

Manifolds. - The manifolds of each system are located upon an adequate foundation and would be subject to equal seismic forces. The single-lift system would have 14 branches under a head of nearly 2000 feet, while each of the two manifolds required for a two-lift system would have 8 branches operating under only one-half this pressure.

Although it is assumed that the manifolds will be designed in accordance with sound engineering practice, these structures inherently are complex with intangible stresses that cannot be analyzed precisely, especially when subjected to seismic shock, including hydraulic forces induced by seismic action. Thus, in spite of careful design, the possibility of a break under extreme conditions cannot be completely ruled out. The hazard of possible rupture is relatively greater for a single-lift manifold with nearly twice as many branches under double the pressure. Furthermore, if a break did occur, the longer uninterrupted length of the discharge pipes in a single-lift contain nearly twice the total volume of water, which would be discharged under twice the head with the consequent potential of much greater damage.

From the standpoint of reduction of seismic hazard to the manifolds, a two-lift system is greatly superior to a single-lift system.

Discharge Lines. - Since the discharge lines for either a single-lift or a two-lift system traverse approximately the same length and are underground in closely similar rock, the hazard of rupture from seismic action would be almost equal. However as was pointed out above, the greater pressure and larger volume of water in the discharge lines of a single-lift system pose a more serious hazard than would two separate lifts.

A two-lift arrangement definitely is superior in this respect.

<u>Intermediate Reservoir</u>. - The site of the intermediate reservoir, common to the alternative two-lift systems, is a highly favorable location. Bechtel geologists state that the foundation is completely adequate for either an embankment or a concrete dam of the height contemplated.

Both the DWR and the Bechtel geologists estimate that the soil cover in the reservoir area and on the surrounding canyon slopes is shallow and that the possibility of major slides is remote. Although some soil creep on the canyon side slopes is evident, Bechtel contemplates removal of material in selected areas to stabilize the slopes and minimize the possibility of debris entering the reservoir from this source. Although the drainage area is less than one-half square mile, provision is made for a debris dam at the upper end of the reservoir. A bypass discharge channel extends along the east side and discharges below the main dam, and a maintenance road and interceptor drainage ditch is provided along the full length of the reservoir on the west side. These provisions are conservatively adequate to eliminate any hazard of material amounts of slope wash or flood debris entering the reservoir.

The normal operating water surface is 21 feet below the spillway lip and 34 feet below the crest of the dam. It is difficult to imagine any hazard of overtopping by seismic induced waves.

The favorable site and the conservative protective measures described provide a high degree of safety. The incorporation of this additional reservoir, required for a two-lift system over and above the more hazardous forebay required in any case, cannot be considered to add substantially to the vulnerability of the system to damage.

Overall Geologic and Seismic Evaluation. - In overall evaluation of geologic and seismic hazards a two-lift system is fully as safe, if not safer, than the alternative single-lift system. Although the Tehachapi Crossing Consulting Board in its report of May 8, 1965 evaluated these hazards differently, it should be noted that this Board arrived at its judgment without benefit of all knowledge now available. At that time, above-ground discharge lines for a two-lift system were compared unfavorably with underground discharge lines for a single-lift system. Information was not then fully available concerning the superior site conditions of the intermediate reservoir and pumping plant locations.

Evaluation of the geologic and siesmic hazards principally on the basis of the number of structures is an oversimplification. In either system the entire ridge alignment will be occupied by structures, either underground or surface. Consideration of the number of structures of a particular type without due regard to the relative site conditions, relative design requirements as regards pressure and volume of water involved and the relative size and specific design of the structures can result in erroneous conclusions.

It is believed that full consideration of all information now available concerning the alternative designs presented herein, would support evaluation of a two-lift system as fully equal to a single-lift system from a geologic and seismic viewpoint.

MECHANICAL DESIGN

Pumps. - The hydraulic and mechanical features are the most important factors affecting the dependability, reliability, efficiency and the ease of maintenance of the pumps. Some of these features can be evaluated by model test, but long term records of actual performance of prototype pumps having characteristics similar to those being considered are a far more dependable measure.

Of the types of pumps suitable for the system presently under consideration, only two-stage, double-flow pumps have a long record of satisfactory operating experience under conditions which bracket all requirements of a two-lift system at Tehachapi. This type of pump has been in use for more than 30 years, with nearly 70 units in 30 different plants in successful operation. This pump has been developed by gradual steps of increase in head, capacity and specific speed, with a corresponding improvement in efficiency. The design of all hydraulic and mechanical features is well documented and no extrapolations are necessary.

All of the principal European pump manufacturers have substantial backgrounds of experience in designing, testing, fabricating and installing large pumps of this type. The performance of many of these installations has been measured in the field and found to be excellent in all respects.

Referring to Figures 1 and 2, a diagram and a photo of the Vianden two-stage pumps (included at end of this chapter), it will be seen that this pump has some advantages inherent in its design. Essentially, it consists of a pair of two-stage pumps back-to-back. Only one-half the flow enters through each of the two suction elbows, thus greatly reducing the problem of shaft interference with flow in the suction elbows and through the impeller eyes. The hydraulic thrust is balanced, minimizing the load on the thrust bearing and simplifying the design of this bearing and the shaft. None of the seals must withstand more than one-half the total head.

When the unit is set horizontally with a split casing, additional advantages are gained. In the first place, positioning of the impellers and seals can be checked accurately during initial installation. Also, this arrangement makes inspection of the internal parts much easier and the pump can be dismantled much more readily for maintenance or overhaul. The horizontal setting makes it readily feasible to unwater the pump during start-up, thus greatly decreasing the starting load. And finally, the horizontal setting lowers the center of gravity and makes possible much more rigid support, resulting in greater structural stability.

Fig. 3 shows a simplified diagram of the five-stage Lunersee pump, which is most nearly comparable to the four-stage pump required for a single-lift at Tehachapi. However, this type of pump does not have any record of operating experience under conditions bracketing the Tehachapi requirements.

The pertinent performance experience of the five major European pumping plants having somewhat comparable large multi-stage pumps is listed and compared in the ensuing tabulation with the proposed single-lift pump for Tehachapi. It will be noted that three of these stations have pumps with the relative head per stage higher than Tehachapi; namely Lunersee, Motec and Tierfehd. However, none has a capacity equalling the Tehachapi requirement, with Lunersee approaching the closest at 46% of the Tehachapi capacity. Likewise, none has a total power output as great as Tehachapi, again with Lunersee rating highest at 70% of the requirement. In specific speed, the most nearly comparable Lunersee pumps have a ratio of 70% of that planned for Tehachapi.

Thus, the Tehachapi requirements are bracketed only in head per stage by existing large multi-stage pumps. Discharge capacity must be extrapolated 100%, power output by 40% and specific speed also by 40%. And, finally, the highest measured efficiency of any existing multi-stage pump is only 89%, so that efficiency also must be extrapolated for a two percent increase to attain the DWR assumed Tehachapi performance.

In development of this pump, no complete four-stage model ever has been tested in the laboratory prior to the

DATA ON MULTI-STAGE PUMPS

Name of Plant	Head Feet	Head per Stage Feet	Head per Stage Relative	Pump Capacity cfs	Pump Capacity Relative	Motor Output HP	Motor Output Relative	Specific Speed N_s	Specific Speed Relative	Efficiency %	Year Installed	Operating Hours	Oper. Hrs. Per Yr.
Tehachapi 1-lift	1983	496	1.00	315	1.00	78,800	1.00	2150	1.00		-----	-----	-----
Lunersee	3151	630	1.27	144	0.46	55,500	0.70	1500	0.70	89	1957-58	13,500	2000
Motec	2065	688	1.39	115	.37	30,700	0.39	1270	0.59	88	1959	7,900	1000
*Ponale	1903	476	0.96	130	0.41	40,000	0.51	1180	0.55		1940	38,500	1000
Tierfehd	1755	585	1.18	97	0.31	22,700	0.29	1750	0.81	88	1963	700	400
Etzel I	1575	315	0.64	92	0.29	20,100	0.26	1428	0.66	87	1947	13,400	800
Etzel II	1575	315	0.64	113	0.36	25,500	0.32	1581	0.74	86	1947	29,200	1700

* Bechtel information varies considerably from this, but DMJM used for simplicity

tests currently being conducted by DWR. And, even in this program, it is proposed to test the model only at approximately 2/3 the Tehachapi head. Bechtel's model tests at NEL clearly show an unpredictable variation of as much as 2% in the relationship between measured efficiency and test speed. Thus, not only have past designs been based upon extrapolations from tests of incomplete models, but it now is planned to evaluate the performance of the four-stage model for Tehachapi on the basis of projections from tests conducted at substantially lower than rated speed. It is Bechtel's opinion, based upon results of tests at NEL, that tests at full speed and full head must be made before the true performance of any pump model can be known.

Furthermore, it is significant that only one manufacturer would be in the position of having designed and tested a complete four-stage pump model suitable for Tehachapi. If this type of pump were selected, it would place this manufacturer in a favored position. It might severely limit competition and at least would introduce the danger that other manufacturers would have inadequate opportunity to attain the best design.

On the other hand, several principal European manufacturers have designed, tested and furnished two-stage, double-flow pumps having characteristics bracketing those required at Tehachapi. They would be in an equal position to bid with a background of adequate experience to assure a good design.

Likewise, as regards the possible alternative single-stage pump, three American manufacturers presently are engaged in designing and testing models suitable for a two-lift system. At least two American and two European manufacturers also have furnished, or are in the process of manufacturing, large capacity single-stage pump turbines for heads approaching or exceeding the Tehachapi two-lift.

Thus, more favorable competitive bidding based upon knowledge gained in actual experience could be expected on two-stage, double-flow pumps or on single-stage pumps.

Fig. 3 also illustrates the extreme complexity of the four-stage pump. The shaft necessarily is long and extends through the eye of the impeller of each stage and through the suction elbow. The shaft must be of sufficient diameter to provide great stiffness in order to safely limit deflections to a small value and to provide a conservative safety factor against resonance vibration at critical speed. But every inch of diameter encroaches upon the waterway of the elbow and the impeller eye of each stage, forcing use of larger diameter waterways and impellers than otherwise would be desirable for best hydraulic design. Thus, a compromise must be made in designing the impeller and waterways and, at the same time, providing adequate mechanical strength. This problem would be magnified in designing a pump of this type for Tehachapi for double the capacity of any similar operating pump and for a specific speed nearly 50 percent higher. Because of the lack of precedent, there is no assurance that these compromises will result in a pump of high dependability and reliability, as well as good efficiency. This risk is considered unnecessary and unwarranted.

It also should be noted that the head seal of a four-stage pump must withstand the full 2000 foot head, four times as much as any seal on a two-stage, double-flow pump.

In summary, a two-stage, double-flow, horizontal pump is clearly much superior to a four-stage, single-flow pump in all major design features. And its use would avoid the substantial risk of not attaining the expected performance.

Valves. - The pump discharge valves for either a single-lift or a two-lift system will present an important design problem. Basically this problem will be greater for valves to withstand 2000 feet of head than for those which will operate at only half this pressure. It is assumed, however, that these problems can be solved successfully in either case and that this item should not have appreciable influence on selection of the system.

Reservoir Controls. - The intermediate reservoir of a two-lift system provides a wide margin of permissible water surface fluctuation and storage. A capacity of 170 acre-feet is available both above and below normal water surface within the permissible range without either spilling or limiting the submergence head or water supply to Pumping Plant No. 2. This is equivalent to 30 minutes of full-capacity system flow in case that either of the two pumping plants should be knocked completely out of operation with the other plant continuing at full capacity. If only one pump in one plant ceased operating, the time interval would be approximately 6 hours to reach maximum operating water level, or over 9 hours to draw down to the minimum.

These extremely conservative allowances provide all necessary flexibility and minimize the problem of monitoring operation of the pumps in both plants.

Overall Evaluation of Mechanical Design. - It is only in the pumps that there is appreciable difference in the dependability and reliability of the mechanical features of the alternative systems. The pumps, therefore, are of utmost importance in selection of the best system.

Whether considered on the basis of feature-by-feature comparison of design, comparison of model test results, or comparison of performance records of all pertinent operating pumps, there can be no reasonable doubt that two-stage, double-flow pumps are superior in every major respect to four-stage pumps. Moreover, two-stage, double-flow pumps are the only type for which all Tehachapi design requirements are completely bracketed by fully proven operating pumps, thus entailing no risk whatever in projection of unproved designs. On the other hand, there is substantial risk in extrapolating existing designs of a four-stage pump to the Tehachapi requirements. Even if as successful as expected, the pump still would be inferior to a two-stage pump. This risk is entirely unnecessary and, in Bechtel's opinion, improper for this system of such vital importance.

ELECTRICAL DESIGN

Motors. - The principal design problem of the motors is that of start-up. Several alternative methods are available. Some of these, however, such as providing individual pony motors, individual starting turbines or torque converters, are expensive and add complex equipment which must be maintained. Other methods, such as across-the-line starting with either full or reduced voltage, complicate the design of the motors and induce heavy stresses, both electrical and mechanical. Even if the across-the-line design problem is solved, the additional features required and the heavy starting loads would increase maintenance and shorten the life of the motors. The DWR and its consultants recognize these severe problems and as yet have not proposed a solution.

The Tehachapi Crossing Consulting Board in its report of May 8, 1965 classifies this problem as "essentially the same for any of the schemes". This was valid for the types of pumps then being considered by DWR and its consultants, namely four-stage, vertical pumps or two-stage, double-flow pumps, also set vertically. The difficulty arises from the fact that to date it has not been considered feasible to start either of these types with the pump unwatered. Even if model investigations should indicate this to be possible, it would not be prudent to rely upon this completely unproven method.

On the other hand, two-stage, double-flow pumps set horizontally, or alternative single-stage pumps set vertically, can be unwatered readily for start-up. This method is in common use. Starting a pump unwatered requires only about one-fourth the starting power of that required to start the pump full against a closed valve.

In either case, however, whether started full or in air, Bechtel favors a synchronous back-to-back arrangement whereby the pumps and motors are brought up to speed by an electrical connection to a turbine driven generator. In this method, the starting inrush is completely eliminated and there is no problem in design of the motors. Likewise, since the internal system is isolated, there is no start-up load on the transformers and transmission lines.

A turbine generator unit having approximately 60 percent the capacity of the pump motor would be required to start a four-stage pump in water. A turbine generator of only one-fourth this capacity could start an unwatered two-stage, double-flow, horizontal pump or a single-stage pump. In either case, two turbine generator units should be supplied to minimize the time of getting all pumps into operation and to provide a spare for use in case one of the starting units was out of service.

Thus, the major electrical problems of start-up would be minimized in a two-lift system.

Other Major Electrical Equipment. - In any case, whether a single-lift system or a two-lift system, the same total number and capacity of incoming transmission lines will be required. In a single-lift system all incoming lines would be concentrated at the forebay plant. In a two-lift system one-half the lines would extend to each of the two pumping plants.

The two switchyards for a two-lift system each would have one-half the total capacity of the switchyard for a single-lift system. Likewise, each of the two switchyards for a two-lift system would occupy only slightly more than one-half the area of the larger switchyard for a single-lift system.

With the exception of the increased capacity required for start-up loads due to across-the-line starting, the same system capacity is applicable to the transformers required for a single-lift or a two-lift arrangement. However, in one case all transformers would be located at the forebay plant, while one-half would be located at each plant in the other case.

It is Bechtel's opinion that separation of the incoming transmission lines, the switchyards and the transformers, with one-half located at each of the two pumping plants of a two-lift system, does not necessarily increase the hazard of either normal operation or catastrophic interruption.

Furthermore, across-the-line starting of pumps in a single-lift system requires larger transformer and circuit breaker capacities than does back-to-back starting of unwatered pumps in a two-lift system.

These advantages of a two-lift arrangement make it slightly preferable as regards the major accessory electrical equipment.

Controls. - In a single-lift system all controls would be located in the same plant. In a two-lift system it is assumed that Pumping Plant No. 2 and the intermediate reservoir would be monitored and controlled from the forebay plant. In either case, it is assumed that the controls would be highly automated and that key elements would be duplicated for greater reliability and would be monitored to be fail-safe. A single-lift system would have fewer controls in a ratio slightly less than the ratio of the total number of pumps in each system.

In either case, however, the controls should not present a major problem. Many complex hydro systems consisting of several unattended generating plants that must be coordinated in operation within very close time and discharge limits are remote-controlled automatically and with high reliability from a single center. There are innumerable examples of much more complicated installations of many different types where the operations are controlled routinely with extremely high dependability, including widespread electrical distribution systems, large electric generating plants powered by both fossil and nuclear fuels, extremely complex refinery and chemical plants and many highly automated manufacturing facilities.

Controls are not a major feature of the project. Adequate controls closely equal in reliability can be provided for either pump-lift system.

Overall Evaluation of Electrical Design. - Although there are some elements of electrical design that slightly favor each of the two alternative systems, it is Bechtel's opinion that either system can be designed to be equally dependable and reliable. The minor differences do not warrant consideration in selection of the best system.

MAINTENANCE AND OPERATION

Pumping Plants. - Aside from normal routine maintenance, the principal problem associated with maintenance of a pumping plant and its associated switchyard will be the possibility of rock falls or slides from the slopes of deep cuts. The forebay plant is located in a very large and deep excavation encompassing the plant on three sides. While DWR estimates that slopes of $1\frac{1}{2}$:1 and 2:1 with berms will be safe, some continuing maintenance of these slopes must be contemplated. It is also possible that earthquakes of catastrophic magnitude could cause serious damage.

A similar situation exists at the site of Pumping Plant No. 2 located on the backbone of the main ridge. However, the rock at this site is stronger than that at the forebay plant, and DWR estimates safe slopes at 1:1 with berms.

However, the alternative site for Pumping Plant No. 2 on the nose of the flat ridge near the dam of the intermediate reservoir is on equally good rock and requires a much smaller volume and depth of cut which, because of the topography, will be subject to almost no hazard from falling material. At this location it also is contemplated that the excavation will be "daylighted" to provide a large level area on the northerly and easterly sides of the plant and switchyard. For these reasons and because this location eliminates the necessity for a surge chamber at the top of the first pump-lift, Bechtel considers this to be the preferable site.

If pumping Plant No. 2 is located at the preferable site described, it is probable that little, if any, additional hazard would be introduced, and only minor additional maintenance would be required for the pumping plants and switchyards of a two-lift system, as compared with a single-lift.

Pumps. - The usual procedure for dismantling a multi-stage, single-flow vertical pump in Europe is to disconnect the shaft, the inlet elbow and the discharge pipe, and to then move the entire pump laterally to a maintenance pit accessible to the overhead crane. The pump then is dismantled by removing the head cover and pulling the rotating parts. This is a difficult and time consuming procedure for this complex pump.

If the pump is encased in concrete for greater structural stability, the rotating parts would have to be removed vertically through the stator of the motor after the rotor had been removed. This not only requires a more extensive dismantling operation but also necessitates substantially greater head room above the motor in order to provide clearance for removing the long pump shaft.

By reference to Fig. 3 it can be seen that the inter-stage impellers, seals and seal-rings are completely inaccessible for inspection or maintenance in a four-stage pump without dismantling the entire pump. Inspection for cavitation on the impellers or checking clearances due to wear on the seal-rings is difficult.

These difficulties are greatly lessened on a two-stage, double-flow, horizontal pump, as can be seen from Figures 1 and 2. The split casing provides convenient access and all parts are readily available to the crane. It also should be noted that head room clearance requirements are minimized.

If the alternative single-stage pump should prove to be suitable for a two-lift system, the maintenance problem would be even further reduced, since this is by far the simplest pump of all. See Fig. 4.

From a maintenance standpoint, pumps of a two-lift system are much superior to those of a single-lift system.

Motors and Major Electrical Equipment. - If back-to-back starting is adopted, there will be little difference in the required maintenance of the motors and major electrical equipment of a single-lift and those of a two-lift system. However, if across-the-line starting is used for either system, shorter life and more maintenance should be anticipated for the motors because of the higher loads and stresses induced during starting.

Manifolds and Discharge Lines. - Under normal circumstances only routine maintenance will be required for the manifold and discharge lines of either system. If a catastrophic break should occur, it is probable that either system would be out of service. However, the greater potential energy locked up in a single-lift system could result in more damage and materially extend the time required for repair and getting back into service.

Potentially, therefore, the manifolds and discharge lines of a single-lift system pose a greater maintenance risk than those of a two-lift system.

Intermediate Reservoir. - In view of the favorable site conditions, the type of structures, the conservative designs proposed and the thoroughly ample protective features incorporated, the intermediate reservoir should require only nominal surveillance and routine maintenance.

Dependability and Reliability of Operation. - In assessing the relative dependability and reliability of a system, many factors should be considered, including: the adequacy of the sites for each individual element, the natural hazards applicable to those sites, the design loads and conditions imposed upon each element, the design features of the structures and equipment, the vulnerability of these structures and equipment to wear or damage, the accessibility of the vulnerable parts for inspection and maintenance, the time required for dismantling and overhaul, and the number of elements which must be maintained and operated.

An evaluation on a mathematical basis in which the results depend primarily upon the number of elements in series, without realistic appraisal of all other factors involved, can be inaccurate and misleading. It is Bechtel's opinion that an evaluation based upon actual long-term experience in operating and maintaining a complex major water system having many different types of structures, including several pump lifts,would be much more realistic and valid.

A two-lift system is superior to a single-lift system in all of the pertinent factors mentioned above, except in the total number of elements. On a realistic and practicable basis, it appears self-evident that a two-lift system could be maintained more easily and economically, could be operated as conveniently and would be more efficient, dependable and reliable than a single-lift system.

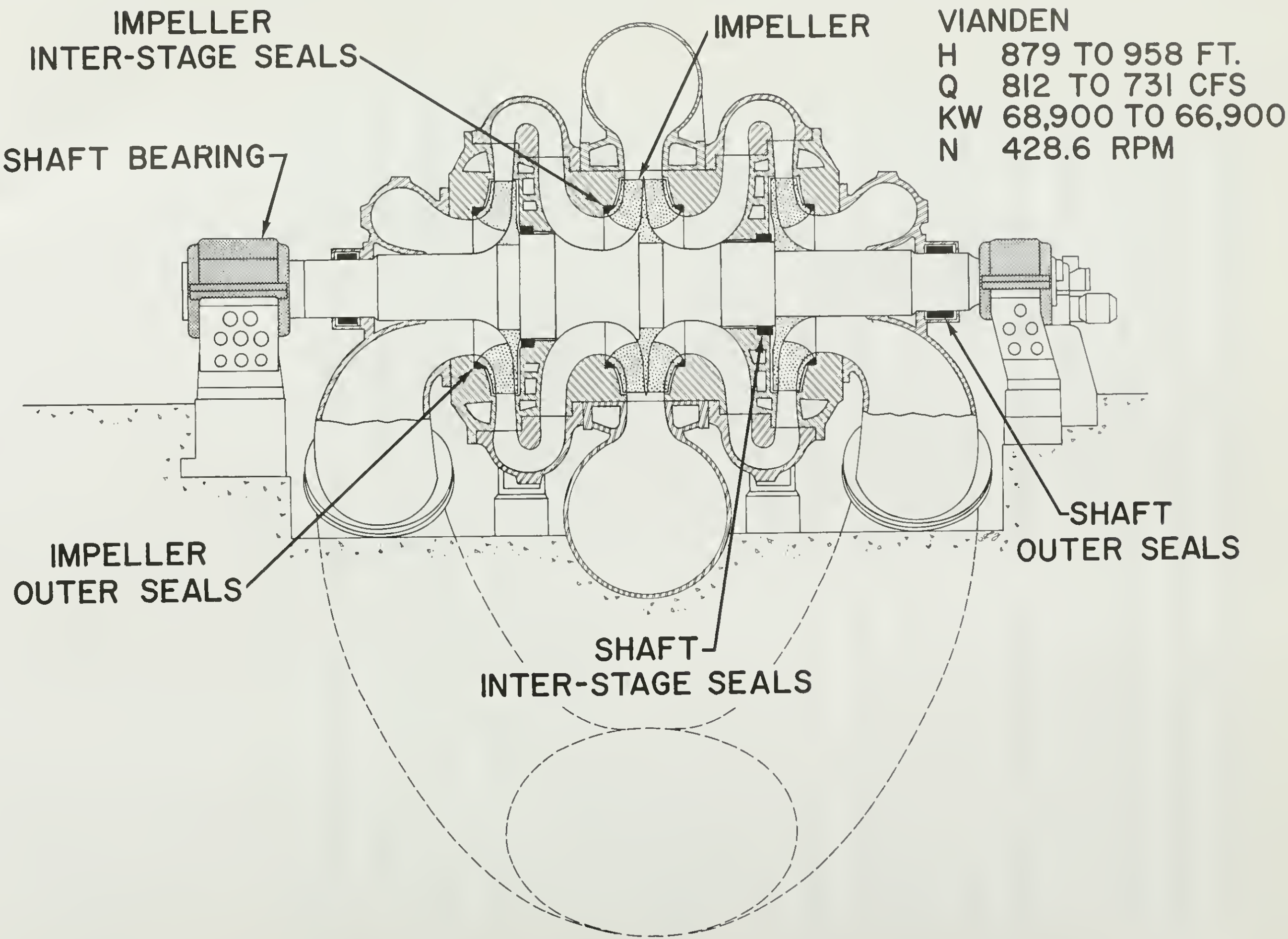
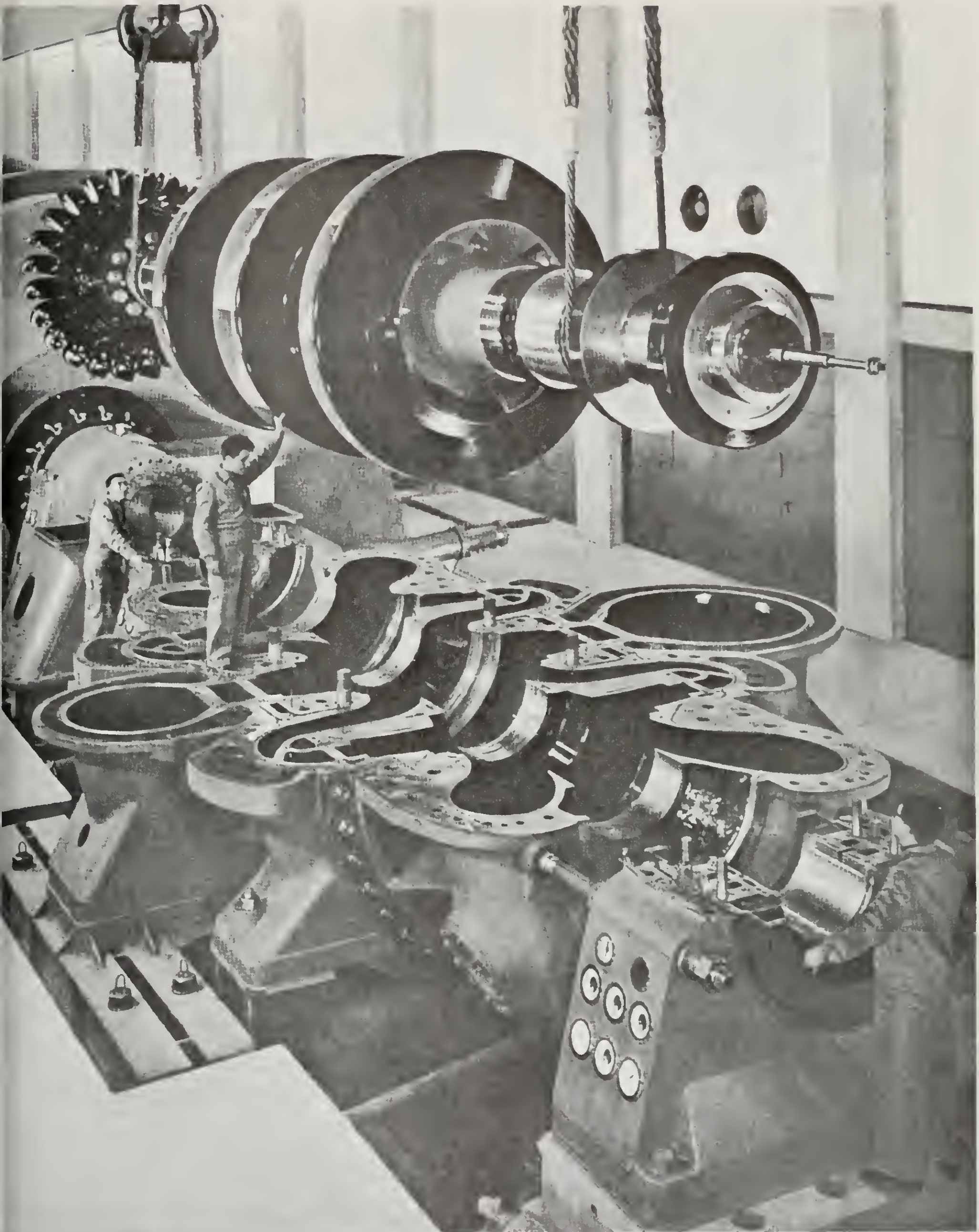


FIG. 1

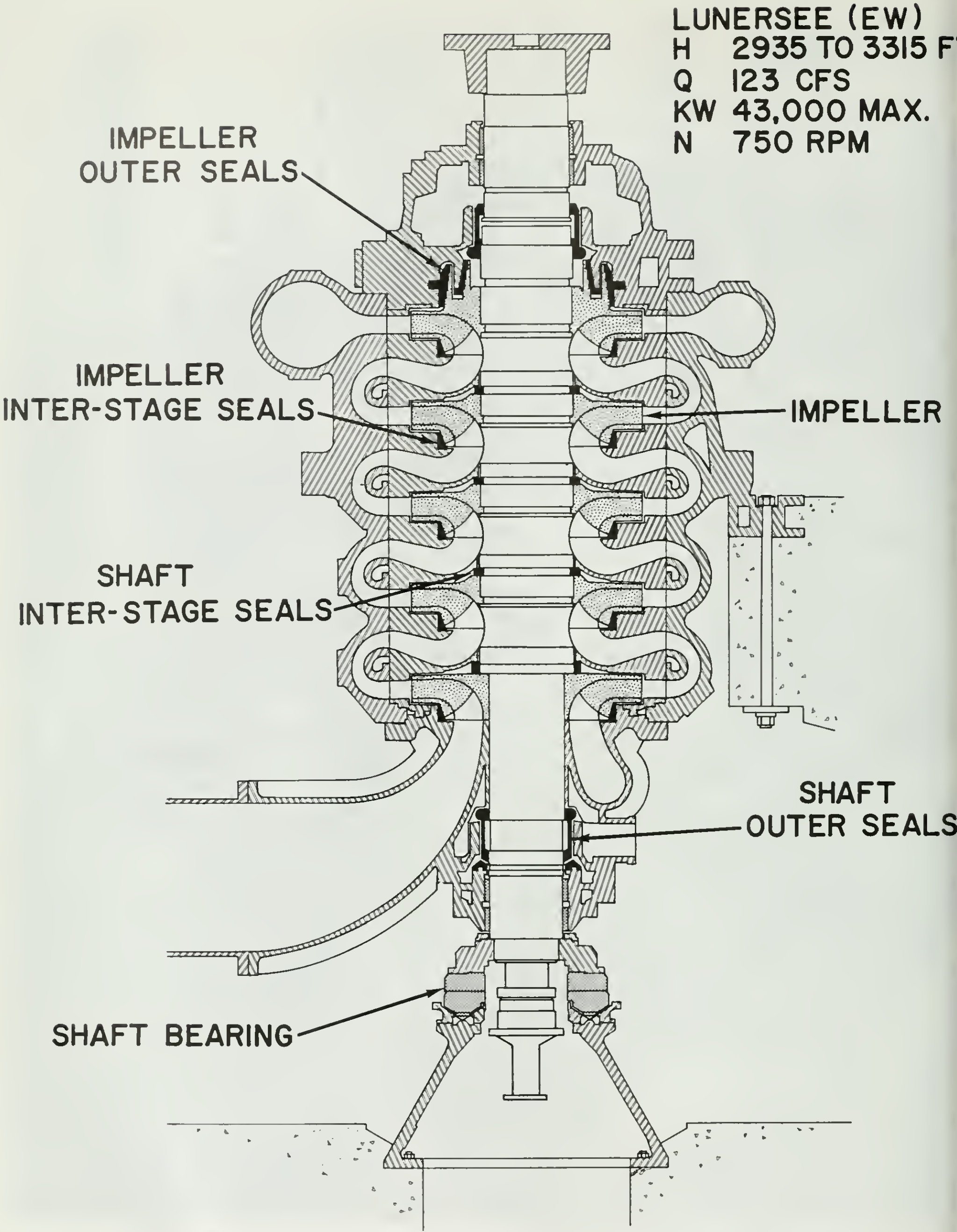
DOUBLE-SUCTION, TWO STAGE PUMP
HORIZONTAL SETTING



INSTALLATION OF A VIANDEN PUMP

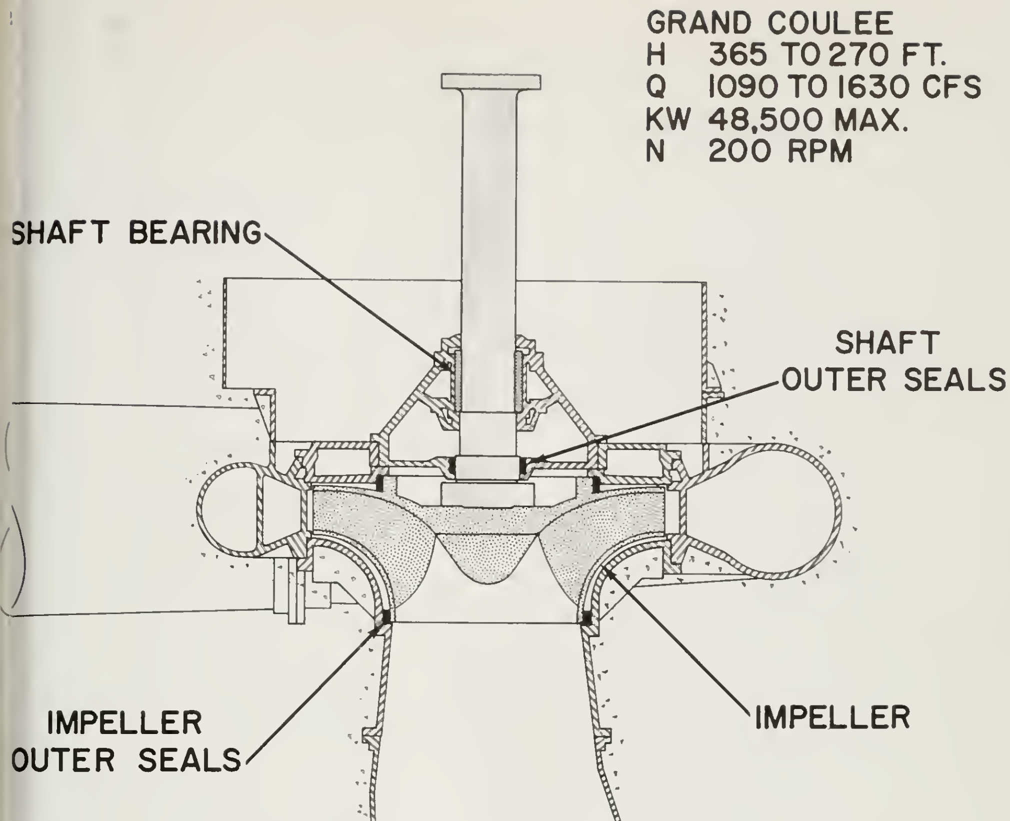
HOTO REPRODUCED BY
OURTESY OF ESCHER WYSS

FIG. 2



SINGLE-SUCTION, FIVE STAGE PUMP

FIG. 3



SINGLE-SUCTION, SINGLE STAGE PUMP

FIG. 4

CHAPTER VII

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

As a result of all the studies presented in previous Bechtel reports, those presented separately in statements by the Bechtel Consultants and the studies and supporting statements presented herein, the following conclusions are offered:

1. Some geological deficiencies have been disclosed recently in the Pastoria Creek location which have caused some experts to question its feasibility and which, in any case, would make systems located along this route less attractive economically.

2. The ridge location provides feasible routes for either a single-lift or a two-lift system, but does not lend itself to a favorable three-lift solution.

3. Cost differences between single-lift and two-lift systems along the ridge are relatively minor and should not enter into selection of the system.

4. Dependability and reliability of operation and ease of

maintenance should be the prime consideration in selecting the system.

5. Two-stage, double-flow pumps with horizontal split casings are superior in all major respects to four-stage, single-flow, vertical pumps. The superior elements include: adequate precedents for design which bracket all Tehachapi requirements, proven reliability of comparable pumps in long term service, full balance of the hydraulic forces, low differential pressures on all seals, high rigidity and structural stability, superior provisions for dismantling to permit inspection and maintenance, proven feasibility of unwatering during start-up and, finally, attractively high efficiency.

6. On the other hand, four-stage, single-flow pumps are the most complicated of the types under consideration and have none of the advantages enumerated above. Furthermore, actual operating precedents for the design of large four-stage pumps bracket the Tehachapi requirements only as regards head. Major extrapolations from existing designs are required in capacity, specific speed and efficiency. This would involve substantial risk that the pump might be less efficient and less reliable than expected.

7. A two-lift system inherently is less hazardous than a single-lift system in several respects, including: lower design pressures on the pumps, valves, manifolds and discharge lines; less vulnerability to displacement or rupture of the pumps and manifolds due to seismic shock; and a lesser degree of potential damage in case of a rupture.

8. Only a two-lift system permits consideration of alternative types of pumps with complete assurance that at least one of these types will meet the requirements.

9. Either a single-lift or a two-lift system would provide adequate flexibility of operation.

10. The only advantage of a single-lift system is the apparent overall simplicity of its basic arrangement, with all pumps and their associated equipment and controls located in a single plant at the forebay. However, this apparent advantage is minor. Highly automatic remote control of innumerable much more complex installations of many different types is accomplished routinely with high reliability. Actually, controls are relatively a very minor item and should not enter into the major decision of selecting the best system.

11. Single-stage, vertical pumps for a two-lift system offer attractive potential advantages in simplicity of design, ease of inspection and maintenance, high efficiency and economy. There is reasonable probability that development of a single-stage pump for the head of the Tehachapi two-lift system could be successfully attained and demonstrated before the pumps must be ordered.

RECOMMENDATIONS

In view of the foregoing and with the full concurrence and support of its consultants, Bechtel recommends that:

1. A two-lift system with underground discharge lines and with Pumping Plant No. 2 located on the flat ridge adjacent to the dam of the intermediate reservoir, somewhat similar to the arrangement shown herein, should be adopted.

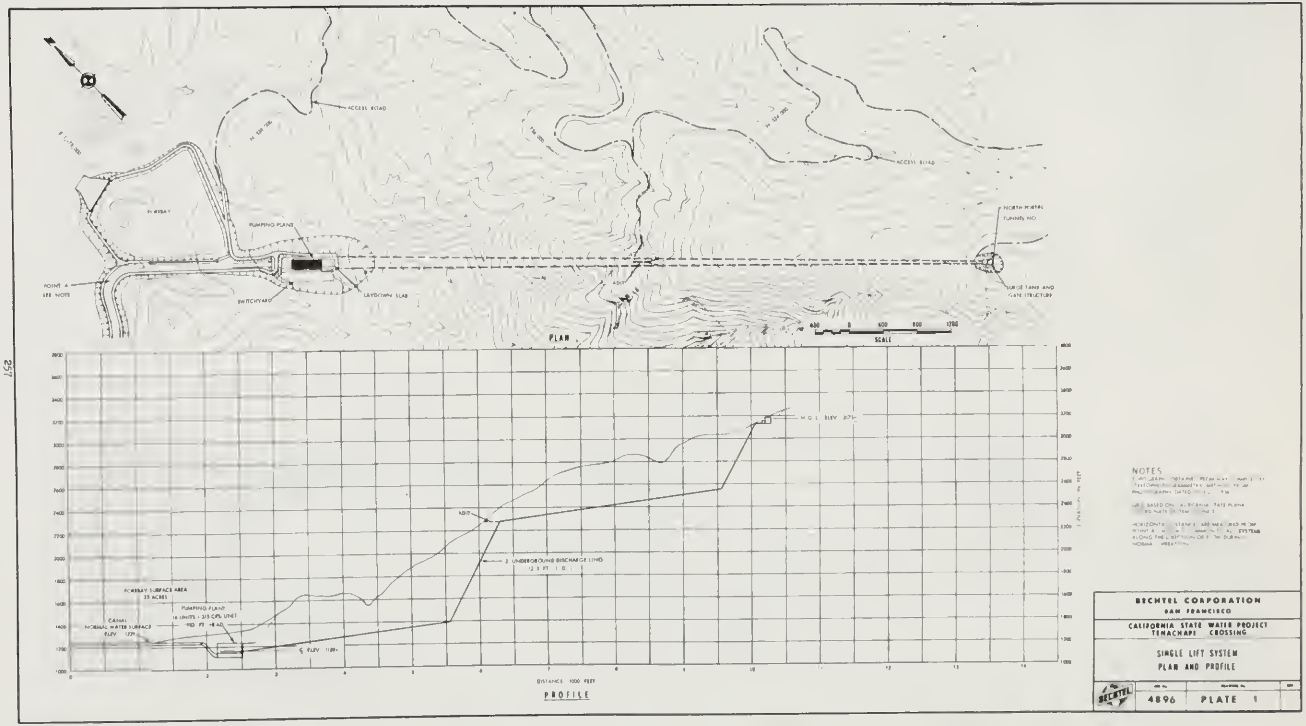
2. Two-stage, double-flow, horizontal pumps should be utilized unless the superiority of single-stage, vertical pumps can be demonstrated prior to the time when the pumps must be ordered.

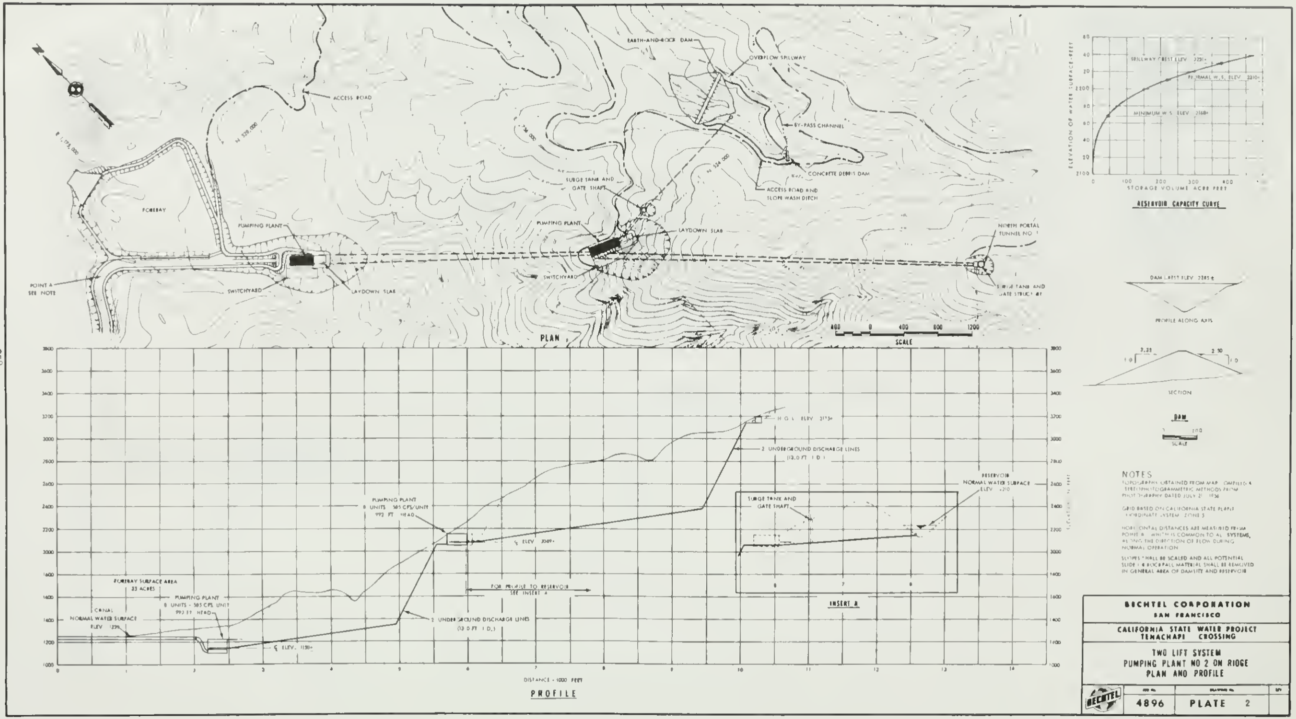
3. A single-lift system utilizing four-stage, single-flow pumps should not be adopted. The substantial risks associated with the pumps, the manifolds and the discharge lines are unnecessary and would be imprudent.

4. The present programs of model testing by DWR and MWD should be continued to conclusion. The DWR models should be made available to MWD as soon as possible for testing at NEL at full prototype head. The DWR single-stage model should also be tested at the head of a two-lift system so that this model and the MWD single-stage models currently being tested can be compared with the DWR two-stage, double-flow model to determine which type is most suitable. It is imperative that all pump models should be tested at full prototype head and full model flow under precisely the same conditions at NEL before selecting the type of pump to be used at Tehachapi.

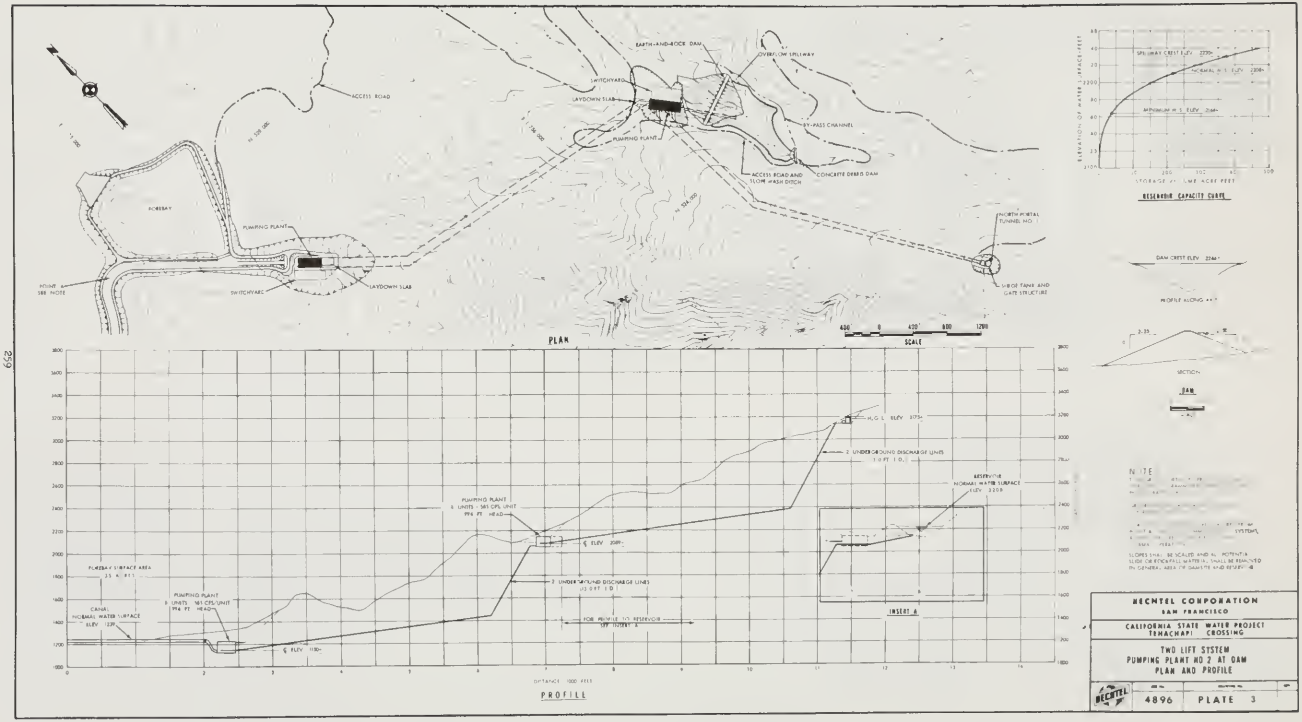
5. Designs for a two-lift system similar to that described above should proceed for all elements, with alternative designs of the pumping plants for two-stage, double-flow horizontal pumps and for single-stage, single-flow vertical pumps. This will permit early award of contracts for the controlling elements in the construction schedule. It also should permit some delay in the

presently scheduled date for selection of the pumps to allow a more thorough evaluation of the alternative types. This is most desirable in view of the importance of the selection.

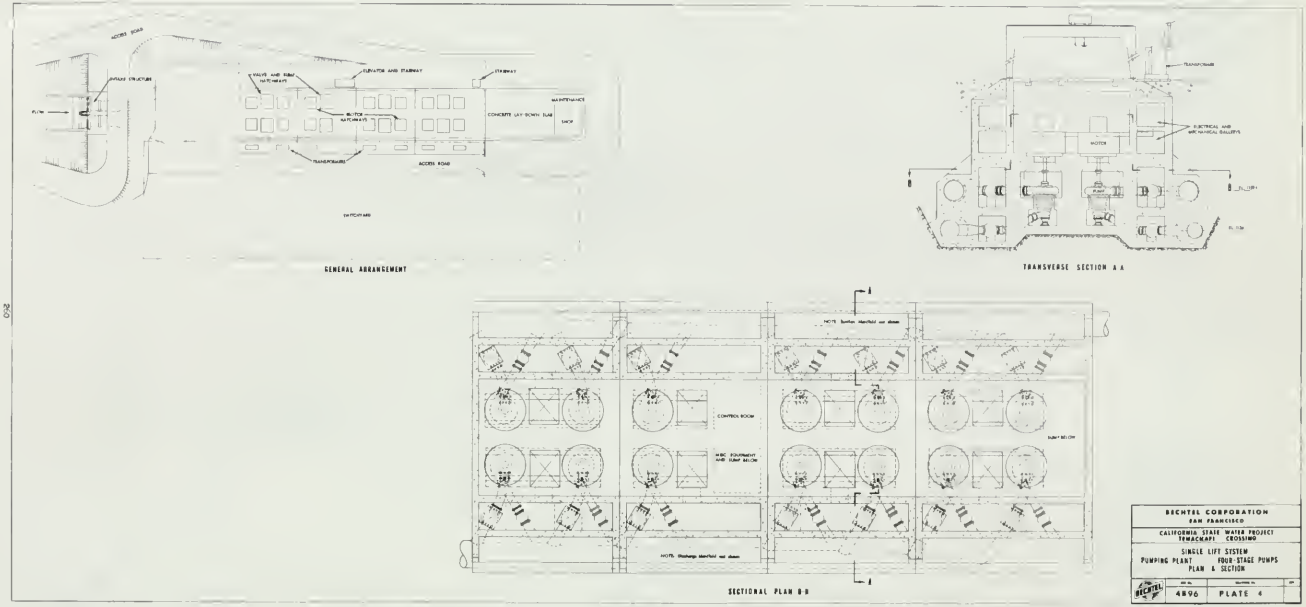

ACCESS ROAD
FOREBAY
PUMPING PLANT
POINT A
SEE NOTE
SWITCHYARD
LAYDOWN SLAB
ADIT
NORTH PORTAL
TUNNEL NO
SURGE TANK AND
GATE STRUCTURE
PLAN
SCALE
NOTES
FOREBAY SURFACE AREA
25 ACRES
CANAL
NORMAL WATER SURFACE
ELEV 1279
PUMPING PLANT
16 UNITS - 375 CFS UNIT
1910 FT HEAD
ADIT
2 UNDERGROUND DISCHARGE LINES
H G L ELEV 3175
DISTANCE 1000 FEET
PROFILE
BECHTEL CORPORATION
SAN FRANCISCO
CALIFORNIA STATE WATER PROJECT
TEHACHAPI CROSSING
SINGLE LIFT SYSTEM
PLAN AND PROFILE
4896
PLATE 1

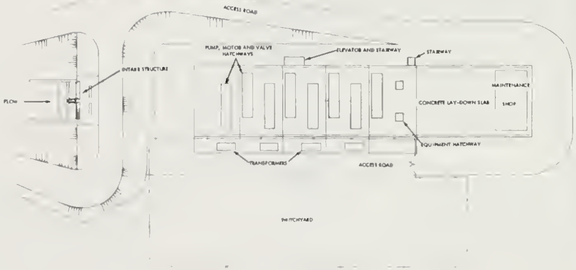


ACCESS ROAD
EARTH-AND-ROCK DAM
OVERFLOW SPILLWAY
BY-PASS CHANNEL
CONCRETE DEBRIS DAM
ACCESS ROAD AND SLOPE WASH DITCH
SURGE TANK AND GATE SHAFT
PUMPING PLANT
LAYDOWN SLAB
SWITCHYARD
NORTH PORTAL TUNNEL NO 1
FOREBAY
POINT A SEE NOTE
PLAN
SCALE
RESERVOIR CAPACITY CURVE
STORAGE VOLUME ACRE FEET
ELEVATION OF WATER SURFACE-FEET
SPILLWAY CREST ELEV 2231±
MINIMUM W. S. ELEV 2168±
PROFILE ALONG AXIS
SECTION
DAM
PUMPING PLANT 8 UNITS 585 CFS/UNIT 992 FT HEAD
2 UNDERGROUND DISCHARGE LINES (12.0 FT I.D.)
FOR PROFILE TO RESERVOIR SEE INSERT A
FOREBAY SURFACE AREA 33 ACRES
CANAL NORMAL WATER SURFACE
SURGE TANK AND GATE SHAFT
INSERT A
DISTANCE - 1000 FEET
PROFILE
NOTES
GRID BASED ON CALIFORNIA STATE PLANE COORDINATE SYSTEM ZONE 5
SLOPES SHALL BE SCALED AND ALL POTENTIAL SLIDE & ROCKFALL MATERIAL SHALL BE REMOVED IN GENERAL AREA OF DAMSITE AND RESERVOIR
BECHTEL CORPORATION
SAN FRANCISCO
CALIFORNIA STATE WATER PROJECT
TEHACHAPI CROSSING
TWO LIFT SYSTEM
PUMPING PLANT NO 2 ON RIDGE
PLAN AND PROFILE
4896
PLATE 2

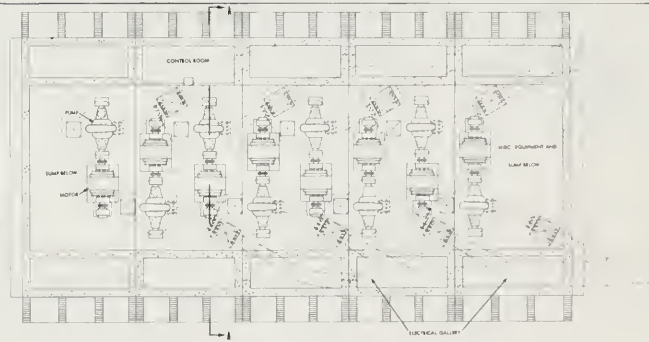


PLAN
PROFILE
SCALE
FOREBAY
PUMPING PLANT
SWITCHYARD
LAYDOWN SLAB
ACCESS ROAD
POINT A SEE NOTE
EARTH-AND-ROCK DAM
OVERFLOW SPILLWAY
BY-PASS CHANNEL
ACCESS ROAD AND SLOPE WASH DITCH
CONCRETE DEBRIS DAM
NORTH PORTAL TUNNEL NO. 1
SURGE TANK AND GATE STRUCTURE
RESERVOIR CAPACITY CURVE
STORAGE VOLUME ACRE FEET
ELEVATION OF WATER SURFACE-FEET
SPILLWAY CREST ELEV. 2230±
NORMAL W.S. ELEV. 2208±
MINIMUM W.S. ELEV. 2164±
DAM CREST ELEV. 2244±
SECTION
DAM
NOTE
SLOPES SHALL BE SCALED AND ALL POTENTIAL SLIDE OR ROCKFALL MATERIAL SHALL BE REMOVED IN GENERAL AREA OF DAMSITE AND RESERVOIR
H.G.L. ELEV. 3175±
2 UNDERGROUND DISCHARGE LINES
RESERVOIR NORMAL WATER SURFACE ELEV. 2208
INSERT A
PUMPING PLANT 8 UNITS - 585 CPS UNIT 996 FT HEAD
℄ ELEV. 2089±
FOR PROFILE TO RESERVOIR SEE INSERT A
FOREBAY SURFACE AREA 35 ACRES
PUMPING PLANT 8 UNITS 585 CPS/UNIT 994 FT HEAD
CANAL NORMAL WATER SURFACE ELEV. 1239
℄ ELEV. 1150±
DISTANCE 1000 FEET
BECHTEL CORPORATION
SAN FRANCISCO
CALIFORNIA STATE WATER PROJECT
TEHACHAPI CROSSING
TWO LIFT SYSTEM
PUMPING PLANT NO 2 AT DAM
PLAN AND PROFILE
4896
PLATE 3

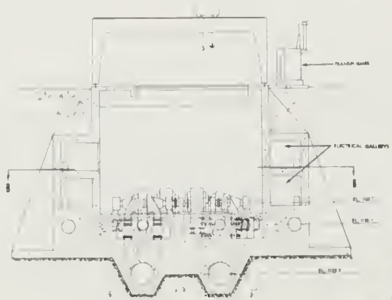

ACCESS ROAD
INTAKE STRUCTURE
FLOW
VALVE AND SUMP HATCHWAYS
ELEVATOR AND STAIRWAY
STAIRWAY
MOTOR HATCHWAYS
CONCRETE LAY DOWN SLAB
MAINTENANCE SHOP
TRANSFORMERS
ACCESS ROAD
SWITCHYARD
GENERAL ARRANGEMENT
TRANSFORMER
ELECTRICAL AND MECHANICAL GALLERYS
MOTOR
PUMP
TRANSVERSE SECTION A A
CONTROL ROOM
MISC. EQUIPMENT AND SUMP BELOW
SUMP BELOW
SECTIONAL PLAN B-B
BECHTEL CORPORATION
SAN FRANCISCO
CALIFORNIA STATE WATER PROJECT
TEHACHAPI CROSSING
SINGLE LIFT SYSTEM
PUMPING PLANT FOUR-STAGE PUMPS
PLAN & SECTION
4896
PLATE 4



GENERAL ARRANGEMENT



SECTIONAL PLAN B B



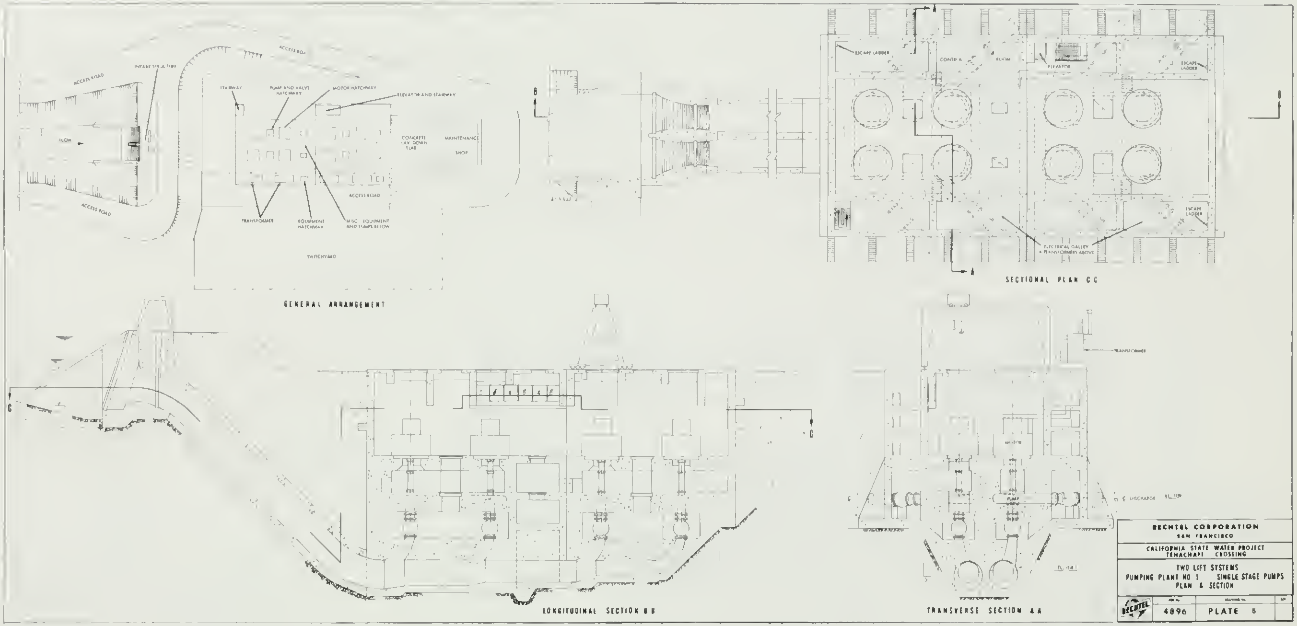
TRANSVERSE SECTION A A

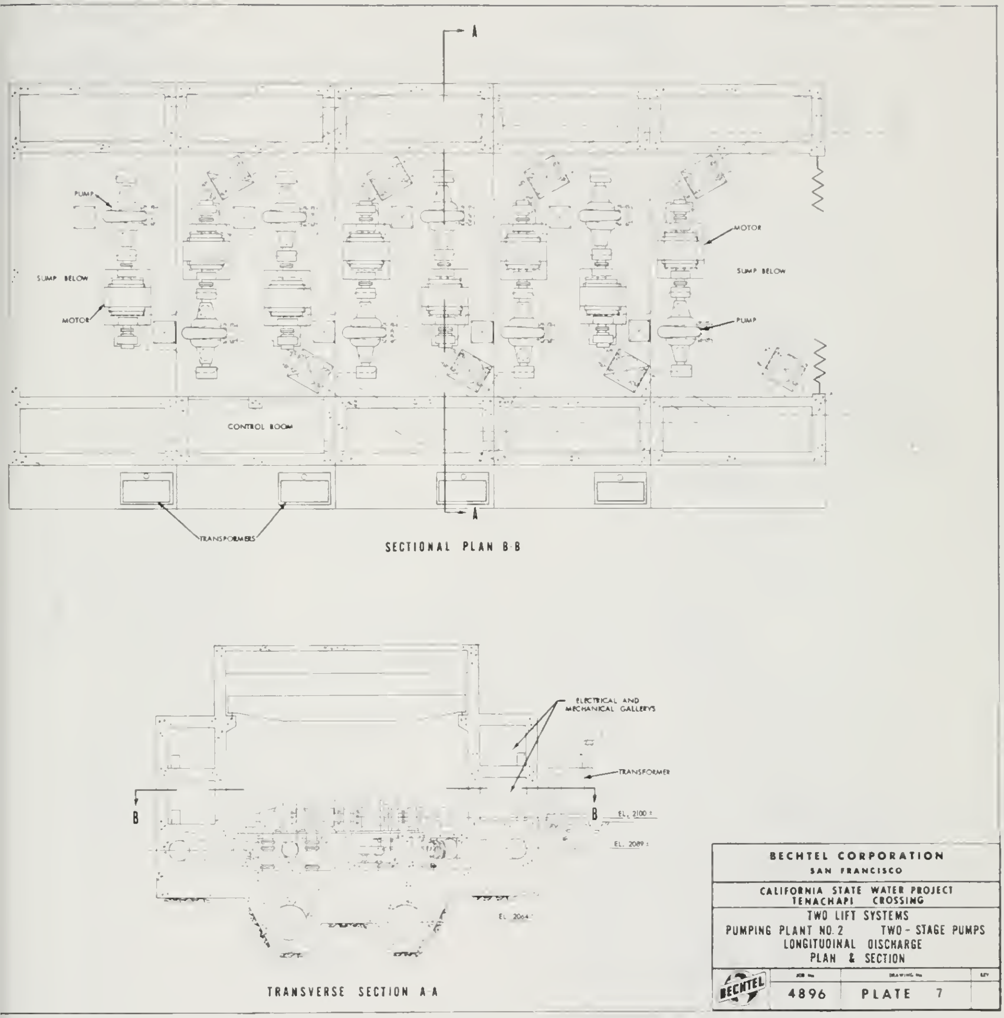
BECHTEL CORPORATION
SAN FRANCISCO

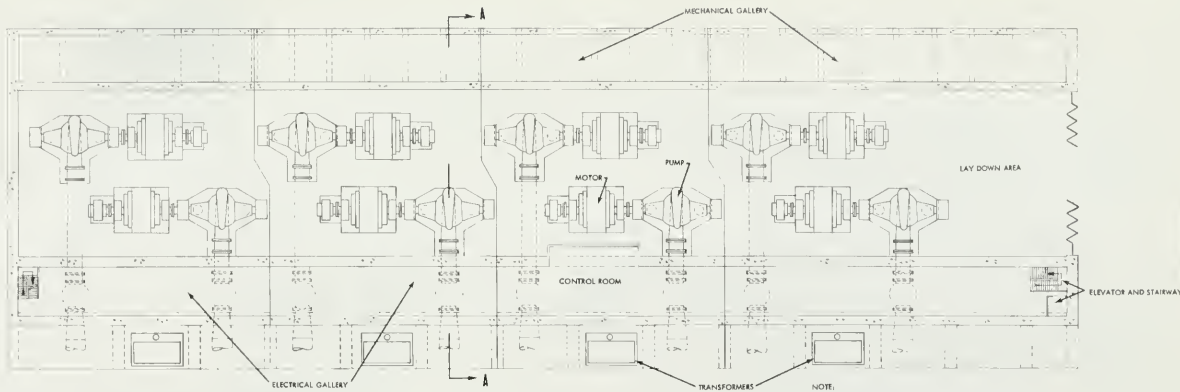
CALIFORNIA STATE WATER PROJECT
TEHACHAPI CROSSING

TWO LIFT SYSTEMS
PUMPING PLANT NO. 1 TWO-STAGE PUMPS
PLAN & SECTION

4896 PLATE 5 1

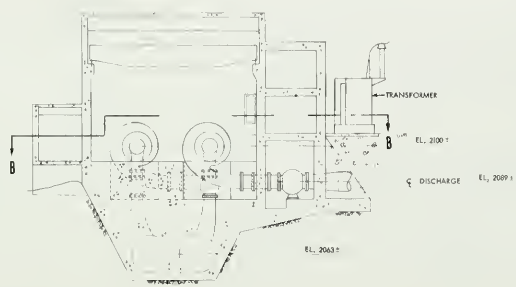

BECHTEL CORPORATION
SAN FRANCISCO
CALIFORNIA STATE WATER PROJECT
TEHACHAPI CROSSING
TWO LIFT SYSTEMS
PUMPING PLANT NO 1 SINGLE STAGE PUMPS
PLAN & SECTION
4896
PLATE 8
GENERAL ARRANGEMENT
SECTIONAL PLAN C C
LONGITUDINAL SECTION B B
TRANSVERSE SECTION A A
ACCESS ROAD
INTAKE STRUCTURE
FLOW
STAIRWAY
PUMP AND VALVE HATCHWAY
MOTOR HATCHWAY
ELEVATOR AND STAIRWAY
CONCRETE LAY DOWN SLAB
MAINTENANCE SHOP
TRANSFORMER
EQUIPMENT HATCHWAY
MISC. EQUIPMENT AND SUMPS BELOW
SWITCHYARD
ESCAPE LADDER
CONTROL ROOM
ELEVATOR
ELECTRICAL GALLERY & TRANSFORMERS ABOVE
MOTOR
PUMP
DISCHARGE


PUMP
SUMP BELOW
MOTOR
SUMP BELOW
PUMP
CONTROL ROOM
TRANSFORMERS
SECTIONAL PLAN B-B
ELECTRICAL AND MECHANICAL GALLERYS
TRANSFORMER
EL. 2100 ±
EL. 2089 ±
EL. 2064 ±
TRANSVERSE SECTION A-A
BECHTEL CORPORATION
SAN FRANCISCO
CALIFORNIA STATE WATER PROJECT
TENACHAPI CROSSING
TWO LIFT SYSTEMS
PUMPING PLANT NO. 2 TWO-STAGE PUMPS
LONGITUDINAL DISCHARGE
PLAN & SECTION
4896
PLATE 7



NOTE:
LOCATION OF TRANSFORMERS, CONTROL ROOM, ELECTRICAL AND MECHANICAL GALLERIES IS SHOWN FOR PUMPING PLANT ON RIDGE. FOR PUMPING PLANT AT DAM, LOCATION IS ON OPPOSITE SIDE.

SECTIONAL PLAN B-B



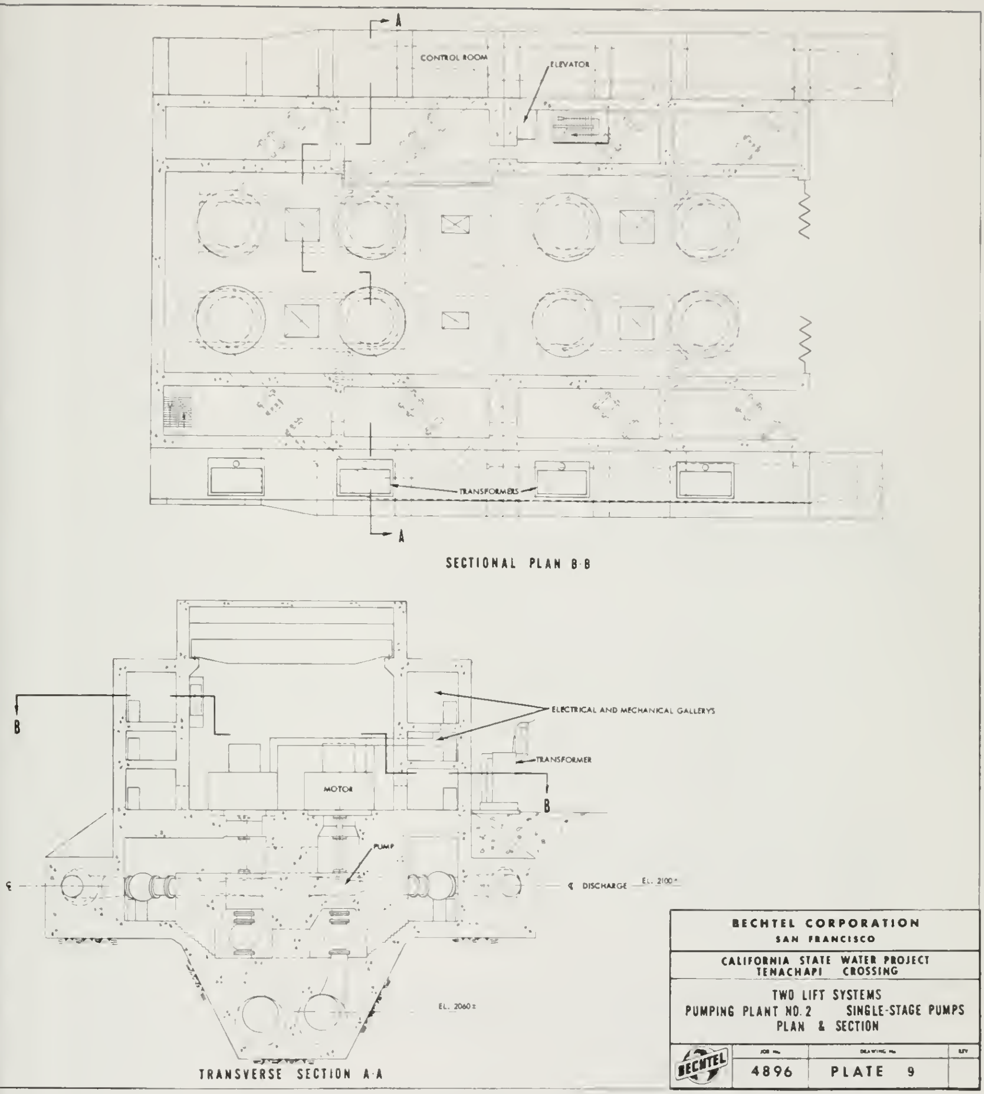
TRANSVERSE SECTION A-A

BECHTEL CORPORATION
SAN FRANCISCO

CALIFORNIA STATE WATER PROJECT
TEHACHAPI CROSSING

TWO LIFT SYSTEMS
PUMPING PLANT NO. 2 TWO-STAGE PUMPS
SIDE DISCHARGE
PLAN & SECTION

JOB No.	DRAWING No.	REV
4896	PLATE 8	1


CONTROL ROOM
ELEVATOR
TRANSFORMERS
A
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SECTIONAL PLAN B-B
ELECTRICAL AND MECHANICAL GALLERYS
TRANSFORMER
MOTOR
PUMP
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EL. 2060±
TRANSVERSE SECTION A-A
BECHTEL CORPORATION
SAN FRANCISCO
CALIFORNIA STATE WATER PROJECT
TENACHAPI CROSSING
TWO LIFT SYSTEMS
PUMPING PLANT NO. 2 SINGLE-STAGE PUMPS
PLAN & SECTION
BECHTEL
4896
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APPENDIX A

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APPENDIX B

CONSULTANTS' COMMENTS

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RCANY 175 12040
GWJUEE BECHTEL
BIBLIETH ZURICHG
27733 BECHTEL

ATTENTION CHIEF HYDRAULIC ENGINEER DICKINSON

REFERENCE TEHACHAPI STOP YOUR LETTER MAY 14 AM DISAPPOINTED TOO AND CONSIDER IT NOT EXTREMELY FAIR TO PICK OUT OF CONTEXT THIS MY ONLY REMARK WHICH IS NOT CLEARLY UNFAVORABLE FOR THE SINGLE LIFT SOLUTION STOP CLEAR DISADVANTAGES OF SINGLE LIFT FOUR STAGE PUMP SOLUTION ARE FIRSTLY LOSS OF EFFICIENCY OF AT LEAST ONE PERCENT PROBABLY MORE STOP SECONDLY BY FAR MOST UNFAVORABLE FOR OVERHAUL OR REPLACE OR REPAIR WORK NEEDING FREE HIGH BELOW OR ABOVE PUMP OR DISMANTLING THROUGH STATOR OF MOTOR STOP THIRDLY DIFFICULT SEALING WITH BAD WATER QUALITY AGAINST HIGHEST PRESSION FOR AXIAL THRUST EQUILIBRATION LEADING TO SUPPLEMENTARY EFFICIENCY DROP STOP FOURTHLY AS EXPENSIVE AS DOUBLE STAGE DOUBLE FLOW PUMPS STOP FIFTHLY INCREASED TECHNICAL DIFFICULTIES IN PENSTOCK DESIGN FOR 2000 FT STOP SIXTHLY EXCLUDED START WITH UNWATERED PUMPS MEANS HEAVIEST CONDITIONS FOR STARTING PROBLEM STOP HOPING SINCERELY RECONSIDERATION OF UNHAPPY RECOMMENDATIONS CONTAINED IN BOARD'S LETTER DATED MAY 8, 1965.

YOURTEL AND PHONE MAY 21 CONTACTED TODAY THREE MANUFACTURERS STOP NOW USING CODE MULTI FOR 4 STAGE SINGLE LIFT STOP DOUBLE FOR TWO STAGE DOUBLE FLOW TWO LIFT STOP SIMPLE FOR SINGLE STAGE TWO LIFT STOP NOW FOLLOW ANSWERS.

ESCHER WYSS BY WALTER MEIER READY TO BID AND SUPPLY WITH OR WITHOUT AMERICAN ASSOCIATE ALL THREE TYPES STOP DOUBLE AND SIMPLE RELATIVELY OPTIMAL EQUAL EFFICIENCIES MULTI CLEARLY LOWEST STOP DOUBLE HORIZONTAL SPLIT HOUSING HIGHEST RELIABILITY SIMPLE ALMOST EQUAL MULTI CLEARLY BADEST STOP SAME RANK CONCERNING MAINTENANCE STOP SIMPLE LEAST EXPENSIVE FOLLOWS MULTI AFTERWARDS DOUBLE STOP GENERAL OPINION DIFFICULT BUT RELATIVE TO PUMP EQUIPMENT NO DOUBT DOUBLE HORIZONTAL SHAFT SPLIT HOUSING STOP

VOITH BY DZIALLAS READY TO BID AND SUPPLY ALL THREE TYPES WITH OR WITHOUT AMERICAN ASSOCIATE STOP SIMPLE AND DOUBLE EQUAL HIGHEST EFFICIENCIES MULTI WITH EVEN NS 2170 AT LEAST 0.7 PERCENT LOWER STOP RELIABILITY WITH CLEAR WATER AND SUFFICIENT NPSH RATHER EQUAL STOP WITH SAND SIMPLE UNFAVORABLE DOUBLE CLEARLY BEST STOP MAINTENANCE ALL RATHER EQUAL IF CORRESPONDING DESIGN STOP PRICES TO RECONSIDER BUT SIMPLE CHEAPEST DOUBLE AND MULTI CLOSELY EQUAL STOP NOT POSSIBLE TO CHOOSE LIFT SYSTEM BECAUSE REASONS BEYOND PUMP DESIGN STOP

SULZER BY RIOUX YOU GOT DIRECT TELEGRAM BID ONLY WITH AMERICAN ASSOCIATE AND SUPPLY RUNNERS FROM WINTERTHUR SIMPLE ONLY BY ALLIS CHALMERS STOP LOWEST EFFICIENCY WITH MULTI BETTER DOUBLE BEST WITH SIMPLE STOP LATTER ONLY WITH CLEAR WATER DOUBLE AND MULTI EQUAL RELIABILITY STOP SAME CONSIDERATION FOR LEAST MAINTENANCE STOP MULTI MOST EXPENSIVE DECREASING DOUBLE TO SIMPLE STOP NO PREFERENCE FOR LIFT NUMBER BUT PREFER MULTI BECAUSE SMALL HEAD PER STAGE STOP

SULZER OPINION SEEMS INFLUENCED BY DMJM MODEL

REGARDS PROFESSOR GERBER

25/5/65 4783 GERBER ML 107 ++++?

JULIAN HINDS
CONSULTING ENGINEER
POST OFFICE BOX 871
SANTA PAULA, CALIFORNIA
93060

May 22, 1965

Mr. M.L. Dickinson
Chief Hydraulic Engineer
Bechtel Corporation
P.O. Box 3965
San Francisco, California

Dear Mr. Dickinson:

After reading the May 8 report of the Techachapi Crossing Consulting Board Report several times, with care, I cannot escape a feeling that its recommendation to proceed immediately with a single-lift four-stage scheme is risky.

I of course, fully appreciate the sincerity with which the Board, the engineers of the State, and their advisors, have reached this conclusion. I hope they also will accept the sincerity of my discussion.

Note. The term "State Group" will be used, as appropriate, to designate collectively the Boards, the Engineers and advisors of the State, who are concerned with the Tehachapi Crossing.

The term "Metropolitan Group" or "M.W.D. Group" will be similarly used.

To begin, I have no desire to condemn a single-lift four-stage scheme per se, nor do I specifically recommend a two-lift system, or any other specific system now.

My position, as it has always been, is to give all promising alternatives a chance in the laboratory, weigh the results carefully against available prototype information and then make a selection on the basis of all the information available, or that can reasonably be made available.

I respectfully submit that in my opinion the Board Report falls somewhat short of this. I hope that I may be granted the privilege of stating my views as clearly and fully as I can, without any implication of offensiveness. The Board, or other representatives of the Department of Water Resources, has not only the privilege, but also the obligation, to respond in the same spirit, if they see fit.

From this foundation I proceed to the details of the Report. All comments are mine alone, made without consultation with others of the Metropolitan Group.

I shall start with the last paragraph on p. 1, which reads: "The planning of the Tehachapi Crossing has reached such a degree of refinement, through eliminating the unsuitable while retaining the feasible elements, that a choice among the schemes and major features of the remaining ridge alternative becomes a matter where judgement plays a major role in arriving at a final engineering preference."

To me this sentence is not convincing, nor do I believe it to be adequately substantiated by what follows in the report.

I understand that a similar, but not identical pump has been found in operation, and that tests have been made on a model. However, promising competitive schemes have not been fully tested.

In my opinion these competitive schemes should not be frozen out before the test program is completed. It is recognized, of course, that the job needs to be gotten under way, but just how urgent is it to make a final decision immediately?

In my opinion there are substantial items of testing that have not been completed, and which can be completed in a relatively short time. I respectfully question the advisability of an irrevocable decision before this testing is completed.

Discussion of Details:

Continuing on the assumption of mutual respect and sincerity, certain other details of the Report are discussed in order.

Question 1, p.2

There seems to be little descension to the idea of abandoning the Pastoria Creek location.

It is my feeling that aside from geology, the Pastoria Creek location offers a practical solution, perhaps the best. However, I yield to the apparently unanimous consensus of the geologist that this route is inacceptable.

It is not clear to me how the abandonment of Pastoria Creek justifies the recommendation under the answer to the same question "....that future design be devoted to the Ridge single-lift scheme..." ignoring all other Ridge alternatives. I was unable to find what seemed to me to be justification for this statement.

I. SITE CONDITIONS, p. 2:

a. Geology. The quality of Ridge geology as discussed in the first paragraph, is generally accepted.

The thesis of the second paragraph, that the effect of geology is primarily dependent on the number of structures is believed to be an over simplfication. The whole length of the Ridge is to be occupied by structures, from the forebay to Tunnel No. 4. An earth movement anywhere along this route could cause trouble which would not be cured or avoided by a 2000 ft. head 4-stage pump, or any other particular pumping scheme.

The third paragraph appears to assume, without substantiation, the geologic problems will be confined largely to pump house structures. Actually, a well located pump house, founded on the best rock available, as it would be, is perhaps little, if any more subject to "geologic" damage than would be sixteen pipe penstock over the same spot.

I am not prepared to absolutely assert the foregoing, but I believe that a pumping station half way up the Ridge, can be made safe.

It is not intended to imply that I recommend the adoption of a two-lift plan now, but I do sincerely feel that such a possibility should be left open until tests are completed.

b. Seismicity p. 2 and 3. The conditions described in the first paragraph are generally accepted. However, if the probability of displacement is "...very low....," why so much concern about a second pumping plant and an intermediate reservoir?

The third paragraph appears to "over reach" a bit. What is meant by "....damage to the small off line reservoir due to shaking .....?" The dam of course must be designed for seismic loads just as any of proposed structures, including the 2000 ft. head pumping plant. Many dams are in worse situations.

If the danager of damaging slides is "....ever present even during light shocks...." then is this not a poor place to build a high head multiple pipe penstock, buried or not?

The statement in the fourth paragraph that the "single-lift Ridge scheme....has marked superiority" is not substantiated, nor would anything that I could say to the contrary be substantiated by data available. What the M.W.D. Group wants is proof of the superiority of whatever plan is selected.

SECTION II, p. 3.

Section II deals with putting the penstocks in tunnels. I agree with this idea for any Ridge scheme.

I do not feel competent to discuss the merits of high stress special steels for field welding.

III MECHANICAL FEATURES, p. 3

a. Pumps. The first paragraph starts with the statement that it is "Our belief....etc." This admitted "belief," possibly a correct one, and certainly a sincere one, ignores the fact that sounder knowledge probably can be made available.

The second paragraph suggest "prototype testing," which would come a bit late in the program.

The quotation from Professor Gerber, in the third paragraph is believed to be misleading, but should be answered by Professor Gerber.

In the fourth paragraph Professor Neal is cited as saying that Manufacturers tests show good correlation with NEL Tests, within 1/2 of one per cent at points of best efficiency. Did this not apply to a comparison of tests between similar examples, not between pumps of totally different characteristices? Professor Neal should respond to this.

Sixth paragraph, what are the expected efficiencies?

Seventh paragraph, is it not possible, or even probable, that this question can be answered by tests in the very near future?

b. Control Equipment, p.5. The "special monitoring" for the two-lift system no doubt can be automated to a large extent. Anyway, the possible need for limited manual monitoring is no excuse for the adoption of a scheme until the relative merits of all schemes are determined.

My single track mind says test first.

IV ELECTRICAL FEATURES, p. 5

I pass this section to others more qualified to discuss it.

V COSTS, p. 6

I agree that securing the best scheme, from all operating points of view, is more important than saving a little money. This does not justify making a premature selection, which may be neither cheapest nor best.

VI DEPENDABILITY

I am heart and soul for dependability, but in my opinion no data is present which shows that some other system might not be more dependable than the proposed 2000 ft. four-stage pump.

VI POINTS OF SUPERIORTY

Alledged points of superiorty of a single-lift scheme over any two-lift plan, listed in subsections "a through h" of Section VI, are discussed as follows:

a. Surface Pumping Plant. "least subject to uncertainties of construction or of access for repairs." Whether true or not this statement is not germane to the subject matter of this communication, as underground plants are not now under consideration.

b. Four-stage Single-lift Pump. "No more complicated than two-stage, double-flow pumps and capable of being ruggedly constructed and reliably operated."

The validity of this statement has been questioned (not refuted) by competent engineers. Anyway this simple statement is not believed sufficient to justify anything but the best, which at the moment is unknown.

c. Single-lift Discharge Lines. The claim is made that these high head lines can be designed "as well as" (not better than) discharge line for other schemes. In the opinion of the writer this awaits proof. Anyway this statement standing alone does not justify the selection of a single-lift scheme.

d. Controls for Single-lift. "Least extensive and least complicated and therefore most reliable."

The "therefore" does not automatically follow the first part of the sentence.

e. Power for Single-lift. Out of my line, but not obvious of any great importance.

f. Water storage for Single-lift. "Requires only a single forebay and therefore at least halves the problems and hazards of reservoir operation."

Over emphasizes reservoir hazard. Such hazard should be small. There will admittedly be some debris from drainage areas, but the forebay drainage areas is much larger than that of the proposed intermediate basin. In either case it may be found desirable to divert debris around the basin.

g. Personel for Single-lift. As discussed elsewhere, the cost of the extra personel required for a two-lift scheme, if any, is trivial, and cannot be cited as an excuse for selecting any pump scheme, prior to the completion of testing.

h. System Operation for Single-lift. Without quoting the paragraph, it is the opinion of the writer that either a one-lift or a two-lift scheme can be operated, and cordinated with upstream pumps.

Question 2, p.7

Answer (not here quoted in full) says that the Board has given "close attention" to the recommendation of Bechtel and others, yet the value, if any, of the pump test program is ignored. Thus any benefits from the relatively large expenditures already made in good faith by Metropolitan Water District, with the knowledge and consent of the State, are vitiated.

My Recommendations.

My recommendations, if it were appropriate for me to make any would be as follows:

a. Get the tunnels and siphons on the Ridge Route under way as soon as practicable or desirable, especially Tunnel No. 3.

b. Hold all items dependent on a selected pumping scheme in abeyance until pump tests are completed to a system selection stage.

c. Unite all hands in an effort to expedite the pump testing program.

d. Follow with such subsequent detailed testing as may be deemed appropriate.

This is herewith submitted to you personally, but with the understanding that it may be extracted, or presented in full to Metropolitan Water District and/or the State, at your discretion.

I hope that these thoughts may be of some value.

Sincerely yours,

Julian Hinds

Julian Hinds

JH/jr

TEHACHAPI PUMP LIFT SYSTEM
COMMENTS ON USE OF MODEL DATA

by
Professor Lawrence C. Neale
May 1965

MWD program at NEL has shown agreement with manufacturers at b. e. p. However, there have been considerable variations at other operating points with these variations reaching values of 2-1/2 percent in several cases. These cases can be picked out in the data presented in NEL report No. 2 on the plots of efficiency versus flow for the six models tested.

In addition there are a number of other variations that should be considered in evaluating a model test series. It has been shown that the location of tapping for pressure measurements particularly on the discharge side of the pump can result in variations of one percent more. This has been borne out in the MWD test program at NEL and in many previous studies. The B-J Grand Coulee Pump studies as reported in ASME document this extremely well.

As indicated in previous reports and shown in the studies at NEL model tests at other than full head conditions must be adjusted or "stepped-up" by some variation of the theoretical relationship ($Q \backsim N$, $H \backsim H^2$, $P \backsim N^3$) in order to compute model performance relative to specified full scale conditions.

The step-up or adjustment has been the subject of much study and much discussion over the years and no hard and fast rule is available today. The tests at NEL show variations between at least each manufacturer in the method and formula to be applied to each model to transfer data to a different head and speed or to a different size.

The test procedures and accepted practice in a given laboratory are also of considerable importance. In several cases during the pump test program at NEL the leakage allowed to leave the model was the subject of discussion. The leakage was in some cases used to balance a thrust on the pump impeller and shaft. The quantity varied considerably and could be treated in the results and performance computations in a number of ways.

1. It was possible to add the measured leakage to the flow and consider the total as the pumped flow. This would result in a relatively high performance.

2. The leakage could be throttled and maintained at some level corresponding to some arbitrary head difference across the casing and this leakage applied to the flow. This system results in a somewhat lower performance.

3. The leakage could be shut off completely and allowed within the casing to find its way back into the flow system. This results in a still lower performance indication.

4. The leakage can just be allowed to flow from the pump casing and no adjustment be made in the pumped discharge as measured in the flow from the pump discharge line. This treatment shows the poorest performance of the four possibilities outlined above.

During the tests at NEL this was observed as indicated and results obtained. The manufacturer from preliminary results of test in his laboratory was using flow plus leakage for his results. This does not seem to be a completely realistic procedure and as such results from the laboratories used must be carefully evaluated.

Finally it should be pointed out that with the data available, the relationship between specific speed and efficiency does exist as well as a relationship between number of pump stages and efficiency. These relationships developed on the basis of experience in field and laboratory are a strong indication of what performance should be expected from the various types of pumps. At present this experience is primarily in the hands of the manufacturers and therefore on a different basis and also not completely available.

Conclusions

1. In the evaluation and application of model test results, the details of the model test procedures must be carefully reviewed.

2. Particular attention to the treatment of leakage rates during tests must be given.

3. Step-up procedures of model test results either to a common model size or to prototype must be based on the best accepted methods available.

4. Results from model tests performed at reduced speed and/or head can be misleading unless the speed-efficiency relationship is completely defined.

Lawrence C Neale

TEHACHAPI PUMP LIFT

COMMENTS ON RECOMMENDATIONS OF

TEHACHAPI CROSSING CONSULTING BOARD

IN LETTER OF MAY 8, 1965 TO

DEPARTMENT OF WATER RESOURCES

ON PREFERABLE SELECTION OF TYPE

OF PUMP AND LIFT ARRANGEMENT

Presented to

Engineering and Operating Committee of
THE METROPOLITAN WATER DISTRICT OF
SOUTHERN CALIFORNIA

Prepared by
RAY S. QUICK, CONSULTANT

BECHTEL CORPORATION
SAN FRANCISCO
MAY 1965

Comments by R. S. Quick, Consultant, Bechtel Corporation, San Francisco, California, on some Engineering Aspects of Pump and Lift Selections Recommended by Tehachapi Crossing Consulting Board in Letter of May 8, 1965 to the California Division of Water Resources.

INTRODUCTION

The following remarks are to supplement Mr. Dickinson's presentation today in regard to the selection of the single-lift four-stage pumps, on the Ridge Route. As the choice of the TCCB in their letter of May 8, 1965 to Mr. A. R. Golze's attention, it is realized that geology and seismic disturbances have been given dominant roles in this work. However, certain factors exist which I believe justify further comment at this time.

DISCHARGE MANIFOLDS

The recommended underground discharge line location will utilize two lines, each with seven branches, under about 2,000 foot head. Any rupture of this system due to seismic action or to defective design, materials or fabrication would result in draining the entire system connected to it. Since work done by a jet of water is the function of the head multiplied by the quantity, it is apparent that the potential damage may be up to four times greater with 2000 foot of head, as compared with 1000 feet, as both the quantities and heads are in the approximate ratios of 2:1.

Quick

The above should be considered in connection with the first paragraph on page 3 of the TCCB letter of May 8, 1965.

MECHANICAL DESIGN - PUMPS AND VALVES

There are few installations available for study in the size and power rating required for the four-stage single-lift pump selected by the TCCB. While optimum efficiency is the goal, it may be difficult or impossible to attain in a unit of the rugged and heavy duty type needed.

The solution of these problems will require information to be obtained from completed model tests. These tests should cover efficiency, head-capacity characteristics, side thrust on impellers, end thrust, and cavitation. These tests also must cover transient conditions arising on starting against a closed discharge valve, normal shutdown and power failure.

Motor starting of a submerged pump involves several difficult electrical and mechanical problems which may outweigh its simplicity. The vertical four stage pump is considered difficult to start unwatered and to prime later, with safety.

The horizontal twin flow, two-stage, or the vertical single-stage design, suitable for the two-lift scheme, does not have this problem, and can be started readily in air and primed later. All such machines with close-running clearances require water cooling of the seals during unwatered operation, to avoid overheating and possible seal damage.

The discharge valves must remain tight and free of objectionable spray leakage for many years, to permit inspection and repair of the pumps. "Wire drawing" or cutting out of seats due to cavitation and erosion may be a serious problem under 2000 foot head. With seven units on a single manifold, this item is most important, as unwatering of the discharge system is not acceptable for seat maintenance. The use of emergency seals is important, but the more serious wear due to 2000 feet of head, as compared with 1000 feet remains.

Inspection of impeller seals is difficult if not impossible in four-stage pumps without complete dismantling. Facilities for handling, alignment and reassembly will require special procedures.

PROTOTYPE EFFICIENCIES

The practice of testing model pumps at full prototype head is to eliminate some of the uncertainties of "step-up" in performance characteristics between model and prototype. Any selection of a specific unit at this time may deny Tehachapi the benefits of the DMJM and MWD model test programs. Such tests should be completed in sufficient detail to insure the selection of the best pump. It is reasonable to predict that the best model will provide the best assurance for maximum prototype efficiency.

Maintenance of this efficiency or unit durability is related to mechanical design. Freedom from vibration, cavitation, and the selection of the most suitable materials will be very important.

Respectfully submitted,

Ray S. Quick

Ray S. Quick

213 Cleveland St.,

Pullman. Wash.

June 5th 1965.

Mr M.L. Dickinson,
Chief Hydraulic Engineer,
Bechtel Corporation,
P.O. Box 3965.
San Francisco. Calif.

Dear Mr Dickinson: Subject: Tehachapi Pumps. Comments on TCCB Report.

Following are my comments on some of the sections of the report dated May 8th 1965 of the Tehachapi Crossing Consulting Board. I regret delay due to my absence from the country.

General, The Pastoria Creek route has apparently been rejected on indubitable geological and seismic grounds. On the Ridge Route, the two lift concept does not have the pre-eminence that it would have on the Pastoria Creek route.

Question 1. I a) and b). The assumption that slides would occur in the small reservoir is not justified, since the two lift scheme if adopted would be designed to avoid every foreseeable possibility.

It is a matter of opinion that a deep conduit is the safest. Troubles have occurred in deep tunnels and would be more difficult to rectify. It would be a sound general principle to keep pressures as low as possible, which would favor the two lift concept.

III a) It is a fact that the pump industry has not yet designed and built pumps of the size and specific speed combination which

ARE CONTEMPLATED FOR THE SINGLE LIFT SOLUTION. THAT IT COULD DO SO IS NOT QUESTIONED, BUT THE DEVELOPMENT WOULD TAKE TIME.

THE SINGLE SUCTION SINGLE STAGE PUMP IS MEETING WITH INCREASED ACCEPTANCE IN EUROPE FOR HEAD SUCH AS WOULD OCCUR IN THE TWO LIFT SOLUTION. THE REASON IS THAT THIS TYPE OF PUMP IS SIMPLE AND CAN BE MADE EXCEEDINGLY RUGGED, AND ACCESSIBILITY IS GOOD. FOR EXAMPLE THE SHAFT CAN BE MADE MASSIVE WITHOUT AFFECTING THE HYDRAULIC PERFORMANCE OF THE PUMP, WHICH IS NOT THE CASE IN A FOUR STAGE PUMP. I HAD THE OPPORTUNITY OF SEEING EXHAUSTIVE STUDIES MADE FOR THE ROBIEI PLANT IN SWITZERLAND, WHICH RESULTED IN THE CHOICE OF THIS TYPE OF PUMP OVER TWO OTHER TYPES CONSIDERED.

YOURS VERY TRULY,

Robert A. Sutherland

ROBERT A. SUTHERLAND.

APPENDIX C

CONSULTANTS' LETTERS OF CONCURRENCE

Table of Contents

HANS GERBER
DIPL. MASCH. ING. ETH.
PROFESSOR FÜR HYDRAULISCHE
MASCHINEN UND ANLAGEN
EIDG. TECHN. HOCHSCHULE
ZÜRICH

ZÜRICH 10/49.
REBBERGSTR. 49
TEL. 051 / 42 69 49 June 9, 1965

Mr. M.L. Dickinson
Chief Hydraulic Engineer
The Bechtel Corporation
220 Bush Street
San Francisco 4, Cal. 94119
U.S.A.

Re: Tehachapi Crossing Project

D e c l a r a t i o n

I know that the Bechtel Corporation is going to work out a paper at the intention of the Metropolitan Water District of Southern California, and with this going later on to the Department of Water Resources of the State of California.

This paper will lead to the conclusion that for the Tehachapi Crossing along the Ridge line a 2-lift solution should be chosen with horizontal shaft double-suction double-stage pumps, unless single-stage pumps can be proved superior before pumps must be ordered.

As this point of view is corresponding exactly with my experiences and conviction I therefore am authorizing the Bechtel Corporation to use my signature for this purpose.

Prof. H. Gerber

Prof. Hans Gerber

HANS GERBER
DIPL. MASCH. ING. ETH.
PROFESSOR FÜR HYDRAULISCHE
MASCHINEN UND ANLAGEN
EIDG. TECHN. HOCHSCHULE
ZÜRICH

ZÜRICH 10/49.
REBBERGSTR. 49
TEL. 051 / 42 59 49

June 9, 1965

Mr. M.L. Dickinson
Chief Hydraulic Engineer
The Bechtel Corporation
220 Bush Street
San Francisco 4, Cal. 94119
U.S.A.

Re: Tehachapi Pumps

Dear Maury,

Thank you for your letter of June 2 which got my full attention, and I would like to answerto you as quickly as possible, as follows.

First of all I have studied carefully all the papers I received with Harold Hart's letter of May 27, and I have also in hand the copy of Escher Wyss' cable. With these papers, with the reports presented at Sacramento on May 5 and 6 and with the letter to Mr. Golzé containing the TCCB recommendations it seems to be possible to take a first decision for the Tehachapi Pump System.

More and more all these arguments seem to me to converge to what was my very first personal feeling after the explanations you gave to me on our first meeting a year ago at Zurich. I hope that this opinion will not be considered as a simple obstination but as a sound and well studied conviction, exactly as I take the opinions and decisions of all the gentlemen of the TCCB, in the same spirit as Mr. Julian Hurds expressed it so well in his letter of May 22 to you.

Therefore I am extremely glad to see that you are not at all feeling to be beaten and to resign, but once more you are going to help the MWD in his fight for the intermediate solution. I think this is a valuable fight the MWD is going to undertake, and I want to try to also make some contributions, which very probably are not new but may help you all in your task.

For this I would like to refer to the items 1 to 3, page 4, of your paper, March 26, 1965 which you worked out for MWD. Taken as a whole I fully agree with it and would only like to strengthen some points.

Item 1: I am fully convinced of the good reasons which are leading to the ridge solution. Even beyond all geological arguments it has always proved better to go upwards as quickly as possible for pump installations.
Here no difference exists to the TCCB letter.

Item 2: It has been said (by myself too) and it is still right, that the Tehachapi Crossing would be first of all a topographical, geological and seismic problem. I think that with item 1 this part of the problem has been reasonably taken into account.
On the other hand a few days ago Mr. Hartmann of Motor Columbus by phone expressed the opinion that he had the feeling as up to date the pump type has been far too much in the foreground. I am not at all of this opinion and I consider it as an opportunistic adaption of opinions to others.
Therefore now, with the ridge solution chosen, other arguments and reasons than under item 1 should be dealt with:
a. Number of lifts and type of pump
b. Operating, maintaining and repairing reasons.

That leads to the conviction that a 2-lift system will highly simplify the whole siting of the power house (means power houses!) and especially the design of the underground "structures": The piping system to be executed without using T1-Steel quality. Such a decision can easily be accepted, but must be taken into account.
For all these reasons a 2-lift system does not seem to show decisive difficulties or disadvantages compared with a 1-lift system.
At the moment finally where a very good solution is existing for the intermediate little storage pond of sufficient volume and which I consider to be necessary and sufficient as well, there is no imperative objection against a 2-lift system from the operating side.
May I mention that there exist numerous multilift systems in Europe for many years. The Grand Dixence Co. with turbines and pumps are running smoothly all their com-

bined plants using for all these interconnected hydraulic systems a kind of computer at the satisfaction of all partners.

Item 3: Dealing with a 2-lift solution there remains the question of type of pump. Perhaps in some years when operating performance of some pumping plants is available (from Robiei, Rönckhausen, Cruachan and others) I would simply claim for the vertical shaft single-stage single-suction pump.
But these experiences are not present, and we are not allowed to work with them as fully valuable proofs. Therefore, with a maximum of long years operating data and experiences, the horizontal (or even vertical!) shaft double-stage double-suction pump type proves to be by far the best solution. All the advantages are well known, and it seems unnecessary to repeat them. May I remind only that for this type of pump experiences are available over more than 30 years from more than 30 pumping plants with almost 70 units, built by the four European Manufacturers and including all characteristics of the future Tehachapi pumps. This will enable those in duty to work out very clear and consistant specifications to make sure that the tenders coming in are all on the same base and of the highest possible technical level.

If I can be of some use for your undertaking to work for a 2-lift solution I would be glad to contribute; please ask me whenever and whatever you want.

As I know the spirit of MWD's and your paper to DWR I do not see any difficulty to give you permission of using my signature at this purpose, and you will find here-enclosed the corresponding declaration.

Best regards,

Hans

H. Gerber

Encl.ment.

525-8002

JULIAN HINDS
CONSULTING ENGINEER
POST OFFICE BOX 871
SANTA PAULA, CALIFORNIA
93060

June 25, 1965

Mr. M.L. Dickinson
Chief Hydraulic Engineer
Bechtel Corporation
P.O. Box 3965
San Francisco, California 94119

Dear Mr. Dickinson:

This letter is to authorize you to use my signature as favoring further study of a two lift pumping system for the Tehachapi Crossing, before the final adoption of a single lift four stage system, or any other system.

The basis of my position, previously set-out in considerable detail, is briefly summarized in the following.

Regardless of all studies made to date, and of the judgement of any of the groups working on the Tehachapi Crossing problem, the facts as I see them are as follows:

(1) The proposed system, in my opinion, goes beyond precedent.

(2) Firm information on efficiency, costs, sturdiness and other structural features of the various possibilities, is not now available for making a dependable choice between the following alternatives:

(a) A single lift system, using four stage pumps.

(b) A two lift system, using two stage pumps.

(c) A two lift system, using single stage pumps.

(3) From information available to me, it appears quite possible that single or two stage pumps in a two lift system may be measurably more efficient than a four stage pump in a single lift system.

(4) The value of efficiency can of course be capitalized, but this should be done with care. Any saving resulting from increased efficiency goes on forever....not just for the repayment period.

(5) The making of a firm selection of any system now would repudiate the very considerable work and expense incurred in good faith by the Metropolitan Water District to date and would deny to the project any benefits from the studies now under way and well advanced toward completion.

(6) Making of a final selection prior to the completion of the test program, on the basis of the unsupported judgement of one man, or a group of men, involves the assumption of a tremendous and unnecessary burden of responsibility.

Recognizing the importance of a proper selection I urge, as I have from the beginning, that we TEST AND FIND THE TRUTH.

Sincerely yours,

Julian Hinds

Julian Hinds

JH/jr

LAWRENCE C. NEALE
OFESSOR OF HYDRAULIC ENGINEERING
CONSULTING ENGINEER
191 Nola Drive
Holden, Mass. U.S.A.

Tel. 617 - 829-4031
617 - 829-4323

29 June 1965

Mr. M. L. Dickinson
Bechtel Corporation
Two Twenty Bush Street
San Francisco, California

Dear Mr. Dickinson:

This is in answer to your letter of 22 June 1965, concerning the Bechtel reports of 5 May to the TCCB and 26 May to MWD. I have reviewed these reports and have in particular studied again the data, both contained therein and referred to in those reports. On the basis of this information, it seems important to restate and emphasize the points involving and dependent upon the model test programs, pertinent to the Tehacapi Crossing.

1. It is apparent that the decision on the choice of pumps should be based on as much model data as can possibly be made available in the time schedule. This data is important because of considerations of efficiency, long time operation and design details such as pump setting.

2. The data that will become available from the high speed test stand at NEL will have a particular bearing on the selection since it will be the only test data available on models operating at the prototype heads. This data will be starting to develop in July 1965. The high speed data has taken on added importance

LAWRENCE C. NEALE
PROFESSOR OF HYDRAULIC ENGINEERING
CONSULTING ENGINEER
191 Nola Drive
Holden, Mass. U.S.A.

Tel. 617 - 829
617 - 829

Mr. M. L. Dickinson 29 June 1965

with the speed efficiency variations as documented by the NEL tests performed during late 1964 and early 1965.

In addition to the items above I wish to add that on the basis of the two reports indicated above I authorize the Bechtel Corporation to affix my signature to the combined document produced from these reports. Such signature is to indicate my concurrence in the conclusions developed therein.

Very truly yours,

Lawrence C. Neale

Lawrence C. Neale

LCN:n

RAY S. QUICK
CONSULTING ENGINEER
57 WOODCROFT ROAD
HAVERTOWN, PENNSYLVANIA 19083
215 SU 9-1672

June 17, 1965

Bechtel Corporation
P.O.Box 3965
San Francisco, California 94119

Attn: Mr. M.L.Dickinson, Chief Hydraulic Engineer

Dear Sir:

Selection of Optimum Pumps for The Tehachapi Crossing Project-Your Reference 4896

This letter is to authorize you to use my signature in recommending further study of the two lift scheme as preferable to the one lift concept, for Tehachapi.

I have reached this conclusion due to the following major reasons:

The two lift scheme can utilize pumps which can be started unwatered, thus greatly reducing the starting duty on the motors.

The two lift scheme will use discharge pipelines which will be far easier to fabricate, due to the lower head.

The potential risk of damage due to a pipeline rupture will be only one-quarter of that of a single lift scheme, for failure in the discharge manifold, due to the fact that the head and flow quantity will be half.

The pump efficiency will be appreciably higher with the two lift scheme, based on information presently available.

Maintenance will be simpler, and the duration between overhauls will be greater, with pumps suitable for the two lift scheme.

The horizontal, double flow, two stage pump, now highly developed in Europe, can be applied to the two lift scheme with complete confidence and without extrapolation in size, power or capacity, provided an appropriate specific speed is used. The efficiency is excellent.

The vertical, single stage, single suction pump has been developed in very large sizes, and for heads in excess of that required for the two lift scheme, for pump-turbine installations in the United States, and soon will be in operation in Europe as well. This type promises to provide low first cost, excellent efficiency, a very simple arrangement and ease of maintenance.

In order to complete comparative studies, in a logical and effective manner, the model tests which are now underway and planned by DMJM and MWD should be completed. Model tests, with appropriate research and development, are the foundation of modern technology in the field of hydraulic machinery. Any conclusion without such information involves undue risk.

I shall be pleased to supplement the above on request.

Very Truly Yours,

Ray S. Quick

Ray S. Quick

Robert A. Sutherland
213 Cleveland Street · Pullman, Washington

Dams
o-electric power
imped Storage

Member Inst C E
Fellow xXxxxr ASME
Fellow ASCE

June 25 1965.

Mr M.L. Dickinson,
Chief Hydraulic Engineer,
Bechtel Corporation,
San Francisco. Calif.

Dear Mr Dickinson: re Tehachapi Pump Study.

I support the recommendation that a two lift solution be adopted for Tehachapi. I also support the recommendation that the pumps be of the double suction two stage type, unless the single suction single stage pump can in the allowable time be proved superior.

My signature may be used for this support.

Reasons for the above recommendations have been presented, and in my opinion these reasons are sound.

I wish to stress three general considerations which are important in prudent planning of such an important project.

a) The two lift solution limits the penstock pressures to approximately one half of that of the single lift, and this is a very important advantage in providing for seismic disturbance.

b) Complete confidence can be felt in the double suction two stage type of pump, since prototype experience is available. On the other hand, a single lift pump of the size and specific speed considered would have to be developed, since prototype experience of such is not available. Without such prototype experience trouble and delays may occur before a satisfactory result is obtained.

C-11

c) THE CHOICE OF A TWO LIFT SOLUTION LEAVES THE DOOR OPEN, AT LEAST FOR A CERTAIN TIME, TO THE POSSIBILITY OF USING A SINGLE SUCTION SINGLE STAGE PUMP, WHICH IS THE MOST SIMPLE AND RUGGED TYPE. CAVITATION AND OTHER MODEL TESTS, AND POSSIBLY PROTOTYPE EXPERIENCE, MAY CONFIRM OR DENY THE POSSIBLE USE OF THIS DESIRABLE TYPE OF PUMP.

IF THE SINGLE LIFT SOLUTION WERE ADOPTED, THE STATE WOULD BE IRREVOCABLY COMMITTED TO THE DEVELOPMENT OF A SUITABLE MULTI-STAGE PUMP.

YOURS VERY TRULY,

Robert A. Sutherland

ROBERT A. SUTHERLAND.

APPENDIX D

MANUFACTURERS' REPLIES RE RELATIVE SUITABILITY OF PUMPS

Table of Contents

TEHACHAPI PUMPS

SUMMARY OF MANUFACTURERS' REPLIES RE RELATIVE SUITABILITY OF PUMPS

In order to secure recommendations from the various pertinent manufacturers concerning the relative suitability of different types of pumps for the Tehachapi Pump-Lift, telegrams were sent on May 21, 1965 to four American manufacturers: Allis-Chalmers, Baldwin-Lima-Hamilton, Byron Jackson and Newport News; and to three European manufacturers: Escher Wyss, Sulzer and Voith, requesting replies to the following questions:

> "With or without European (American) associates would you bid on and supply firstly four-stage pumps for single-lift, secondly two-stage pumps for two-lifts, thirdly single-stage pumps for two-lifts?
>
> "In your opinion, which would be firstly most efficient, secondly most reliable, thirdly require least maintenance, fourthly least expensive?
>
> "Which pump-lift system and type of pump would you recommend?"

Telegraphic replies were received from all seven manufacturers, although several did not anwer all of the questions. In response to the last question, Byron Jackson and Newport News both recommend a two-lift system with single-stage pumps, Escher Wyss recommends a two-lift system with two-stage, double-flow pumps and Sulzer recommends a single-lift system with four-stage pumps. Thus, three of the four manufacturers which replied to this question recommend a two-lift system, while only one favors a single-lift system.

It also is of interest to note that all of the manufacturers which replied to the applicable questions rate the four-stage pump as relatively the least efficient and the most expensive. The replies indicate that three bids would be received from combinations of American and European associated manufacturers on either four-stage or two-stage pumps and that six bids might be received from manufacturers bidding alone on single-stage pumps for a two-lift system.

The replies to the questions concerning efficiency, reliability, maintenance and cost are tabulated on the following page.

TABULATION FOR

SUMMARY OF MANUFACTURERS REPLIES RE RELATIVE SUITABILITY OF PUMPS

Manufacturer	Relative Order of Preference												Bid Alone			Bid with Assoc.		
	Efficiency			Reliability			Maintenance			Cost								
	4-stg.	2-stg.	1-stg	4-stg.	2-stg.	1-stg	4-stg	2-stg.	1-stg.	4-stg.	2-stg.	1-stg.	4-stg.	2-stg.	1-stg.	4-stg	2-stg.	1-stg.
Replies as Received																		
American																		
Allis-Chalmers	3	2	1	-	-	-	-	-	-	2	2	1	-	-	X	X	X	-
Baldwin-Lima-Hamilton	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	X	X	-
Byron Jackson	-	-	1	-	-	1	-	-	1	-	-	1	-	-	X	-	-	X
Newport News	2	1	1	-	-	1	-	-	1	-	-	1	-	-	X	X	X	-
European																		
Escher Wyss	-	1	-	-	1	-	-	1	-	-	-	1	X	X	X	X	X	X
Sulzer	3	[illegible]	1	1	1	2	1	1	2	3	[illegible]	1	–	–	–	X	X	-
Voith	3	1	2	2	1	[illegible]	3	[illegible]	1	3	[illegible]	[illegible]	X	X	X	X	X	X

BECHTEL SF

ATTENTION M L DICKINSON

ALLIS CHALMERS ANSWERS AS FOLLOWS TO THE QUESTIONS RAISED IN YOUR TELEGRAM OF MAY 21 QOXXX1965 RELATING TO TEHACHAPI PUMPS

FIRSTLY, ALLIS CHALMERS WOULD RESPOND TO AN INVITATION TO BID ON FOUR STAGE PUMPS FOR SINGLE LIFT UTILIZING SULZER DESIGN ASSISTANCE AND ALLIS CHALMERS MANUFACTURE

SECONDLY, ALLIS CHALMERS WOULD RESPOND TO AN INVITATION TO BID ON TWO STAGE PUMPS FOR TWO LIFTS UTILIZING SULZER DESIGN ASSISTANCE AN ALLIS CHALMERS MANUFACTURE

THIRDLY, ALLIS CHALMERS WOULD RESPOND TO AN INVITATION TO BID ON SINGLE STAGE PUMPS FOR TWO LIFTS UTILIZING ALLIS CHALMERS DESIGN AND MANUFACTURE

WE RESPOND TO YOU XXX YOUR FURTHER QUESTIONS AS FOLLOWS

1. ALTHOUGH EFFICIENCY IS ONLY ONE FACTOR IN DESIGN SELECTION MODEL TESTS WIXXX WHICH WE HAVE CONDUCTED AND WHICH YOU HAVE A

KNOWLEDGE OF INDICATE THAT SINGLE STAGE PUMPS ARE SLIGHTLY MORE EFFICIENT THAN EITHER TWO STAGE OR FOUR STAGE PUMPS ALSO, MODEL TESTS BY OTHERS SEEM TO INDICATE THAT TWO STAGE PUMPS ARE SLIGHTLY MORE EFFICIENT THAN FOUR STAGE PUMPS

2. ANY OF THE THREE TYOXXX TYPES OF PUMPS UNDER CONSIDERATION WOULD CARRY EQUAL WARRANTY PROVISIONS AND ALL BE QUITE RELIABLE IF BUILT BY ALLIS CHALMERS. EXTENSIVE STUDIES OF THE THREE TYPES OF PUMPS IN SERVICE AT VARIOUS INSTALLATIONS AROUND THE WORLD HAVE BEEN MADE BY YOURSELVES AND THE STATE D W R AND SHOULD HAVE PROVIDED THE INFORMATION ON RELIABILITY YOUR REQUIRE

3. AGAIN, THE EXTENSIVE STUDIES DONE BY YOURSELVES AND THE STATE D W R ON INSTALLATIONS AROUND THE WORLD SHOULD HAVE PROVIDED THE KNOWLEDGE ON MAINTENANCE YOU REQUIRE

4. FROM INFORMATION WE HAVE ALREADY PROVIDED YOU OUR PRELIMINARY STUDIES INDICATE SINGLE STAGE PUMPING EQUIPMENT IS LESS EXPENSIVE THAN THE OTHER TWO TYPES THE TWO STAGE AND FOUR FXXX STAGE PUMPING EQUIPMENT IS APPROXIMATELY EQUAL IN PRICE

OVERALL PROJECT ECONOMIC STUDIES WHICH YOU HAVE MADE WOULD TEND TO INDICATE WHICH SCHEME IS MOST SATISFACTORY AND ECONOMICAL AS MENTIONED ABOVE ALLIS CHALMERS STANDS PREPARED TO RESPOND TO AN INVITATION TO BID ON ANY OF THE THREE TYPES OF PUMPING EQUIPMENT

ALLIS CHALMERS MFG CO

W J MCCORMACK

MANAGER OF MARKETING

HYDRAULIC PRODUCTS DIV

W E SCOTT

MANAGER CONTRACTOR SALES

END OR GA717 59014229

509   5-24-65   5-24-65

3\$ OR GA

P

WUG094 (TLX268) THIS MSG RECD DIRECT FROM SENDER VIA WU TELTEX

TLX PD EDDYSTONE PENN MAY 24 203P PDT

BECHTEL CORP

220 BUSH

M L DICKINSON

TEHACHAPI PUMPS DEPT OF WATER RESOURCES STATE OF CALIF

REFERENCE IS MADE TO YOUR TELETYPE OF MAY 21 1965 BLH AS A LONG ESTABLISHED DESIGNER AND MANUFACTURER OF HEAVY EQUIPMENT AND ESPECIALLY RELATED TO HYDRAULIC EQPT HAS EVERY INTENTION TO BID FOR THE FURNISHING OF THE TEHACHAPI PMPXXX PUMPS. WE WOULD PREFER TO BID AS A SOLE SUPPLIER HOWEVER IF CONDITIONS ARE SUCH THAT THE SPECIFICATIONS CALL FOR EQUIPMENT BEYOND OUR EXPERIENCE WE WOULD UNDOUBTEDLY HAVE NO CHOICE BUT TO WORK WITH J M VOITH AS OUR ~~XX~~ LICENSEE. IN ANSWER TO THE SECOND PART OF YOUR TELETYPE WE FIND IT DIFFICULT TO ANS AS WE ARE NOT FULLY COGNIZANT OF THE NATURE OF THE QUESTION NOR ARE WE IN A POSITION TO EVALUATE THE VARIOUS PUMP SCHEMES DUE TO LACK OF SUFFICIENT TIME

G V ARATA BALDWIN LIMAHAMILTON CORP

255PMP

\5

BECHTEL SF

BYRON JACKSON PUMPS, INC. LOS ANGELES, CALIF. 213-773-5636

MAY 24 1965

TO M L DICKINSON	FROM E E LINDROS
BECHTEL CORP .	BYRON JACKSON PUMPS,.
SAN FRANCISCO	LOS ANGELES

REURWIRE TEHACHAPI

WITH OR WITHOUT EUROPEAN ASSOCIATES

FIRST BJ WOULD NOT BID ON FOUR STAGE PUMPS FOR SINGLE LIFT.

SECOND BJ WOULD NOT BID ON TWO STAGE PUMP-SINGLE CASE FOR TWO LIFTS.

THIRD BJ WOULD BID ON SINGLE STAGE PUMPS FOR TWO LIFTS. IT IS CONSIDERED OPINION OF BYRON JACKSON THAT THE COMBINATION OF SINGLE

STAGE, SINGLE SUCTION PUMPSWOULD

FIRST   BE MOST EFFICIENT.

SECOND BE MOST RELIABLE.

THIRD   REQUIRE LEAST MAINTENANCE.

FOURTH BE LEAST EXPENSIVE.

BJ RECOMMENDS USE OF SINGLE STAGE PUMPS.

OF THE THREE PUMP LIFT SYFTEMS SPECIFIED IN YOUR WIRE, BJ
UNEQUIVOCALLY RECOMMENDS THE SINGLE STAGE PUMPS FOR TWO LIFTS.
HOWEVER, BJ ALSO BELIEVES THAT SINGLE STAGE PUMPS IN SERIES
OFFER ADVANTAGES OVER FOUR STAGE PUMPS FOR A SINGLE LIFT
THAT SHOULD BE CONSIDERED.

OPER IN MSG FIFTH LINE FROM BOTTOM SIXTH WORD SHD BE SYSTEMS PLS FIX TU
GA OR END PLS ACK

BECHTEL SF

BECHTEL SF

TWX 9 NEWPORT NEWS VIRGINIA 5-25

M L DICKINSON

BECHTEL CORP

SAN FRANCISCO, CALIF

REURTEL 5-25 TEHACHAPI MULTI-STAGE PUMP DESIGN WOULD BE IN COLLABORATION WITH ESCHER WYSS FOR MANUFACTURING AT NEWPORT NEWS. SINGLE-STAGE PUMP DESIGN AND MANUFACTURING AT NEWPORT NEWS. GUARANTEED PROTOTYPE EFFICIENCY FOUR-STAGE SINGLE-LIFT ABOUT 89.4. TWO-STAGE TOW-LIFT AND SINGLE-STAGE TWO-LIFT ABOUT 91. CONSIDERING ALL FACTORS INCLUDING NUMBER SEALS INVOLVED, CRITICAL AND SPECIFIC SPEED, CASING JOINTS, BELIEVE SINGLE-STAGE TWO-LIFT PUMP OFFERS MOST RELIABILITY LEAST OUTAGE TIME AND LOWEST PUMP EQUIPMENT COST ASSUMING 16 SINGLE-LIFT UNITS AND 18 DOUBLE-LIFT UNITS REQUIRED.

BASED ON ABOVE FACTORS MUST RECOMMEND SINGLE-STAGE TWO-LIFT SCHEME.

R HIAL PEPPER

NEWPORT NEWS SHIPBUILDING AND DRY DOCK CO

710-880-0007 CLG

END AND TU

CORR. 5TH LINE TWO-STAGE TWO-LIFT

ECANY 174 C5436

27733 BECHTELMOM PSE+?

ESCHERWYS ZCH 66

27733 OECHTEL COPIES TO:..ML DICKINSON

ESCHERWYS ZCH BB 23/5/65 28.5.64 13.50 H

TEHACHAPI 21 AND 27 ESCHERWYSS ANSWERED TO PROF. GERBER ALREADY ON 24 TH STOP WE REPEAT OUR ANSWERS STOP ESCHER WYSS WOULD BID ON AND SUPPLY ALL THREE TYPES OF PUMPS WITH OR WITHOUT AMERICAN ASSOCIATES STOP ACCORDING OUR OPINION THE DOUBLE FLOW TWO STAGE HORIZONTAL PUMP IS MOST EFFICIENT AND MOST RELIABLE AND REQUIRES LEAST MAINTENANCE STOP THE CHEAPEST IS THE SINGLE FLOW SINGLE STAGE PUMP STOP ESCHERWYSS RECOMMENDS TWOWIREWVSYSZEM WITH DOUBLE FLOW TWO STAGE PUMPS

ESCHERWYSS ZURICH/ WTHME

+

27733 OECHTEL

ABOVE IS FOR MR. M.L.DICKINSON PLEASE

+

27733 BECHTEL

ESCHERWYS ZCH B

D-11

COPIES TO:..ML DICKINSON

WU3014 108 PD INTL

CD WINTERTHUR/TLX VIA WUI MAY 24 1817

LT BECHTEL CORP

SFRAN

ATTENTION DICKINSON ALTERNATIVES CALLED ABEL FOURSTAGE ONE LIFT BAKER TWO STAGES TWO LIFTS CHARLIEONE STAGE TWO LIFTS STOP FIRSTLY SULZER WOULD SUPPLY IMPELLERS AND BID WITH ALLISCHALMERS ON ABEL AND BAKER SECONDLY DECREASING EFFICIENCIES CHARLIE BAKER ABEL STOP RELIABILITY AND MAINTENANCE ABEL BAKER ARE EQUIVALENT BUT CHARLIE ONLY WITH CLEAN WATER STOP UNDER IDENTICAL COMMERCIAL CONDITIONS DECREASING SELLING PRICE PER UNIT ABLE BAKER CHARLIE THIRDLY WE STRESS THAT PUMP TYPE SELECTION STILL SUBORDINATED TO LIFT SYSTEM DECISION WHICH BEYOND OUR COMPETENCE STOP FOR PUMPS WE RECOMMEND ABEL BECAUSE LOWER STAGE PRESSURESINGLE SUCTION STAGE AND HIGHER PLANT CAPACITY WHEN SINGLE OUTAGE

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TEHACHAPI

OUR REF.: TP 512 HS

REFERING TO A CABLE FROM BECHTEL CORP.NO. 121/120 21 1403 OF MAY 24 WE ASK YOU TO IMMEDIATELY TRANSMIT THE FOLLOWING TEXT TO MR. DICKINSON IN BECHTEL CORP.:

1.
EVIDENTLY WE ARE INTERESTED IN SUPPLYING THE PROTOTYPE PUMPS FOR TEHACHAPI, FOR ALL 3 TYPES.

2.
ON THE BASIS OF CONDUCTED MODEL TESTS EXPECTED EFFICIENCY 93 0/0 FOR DOUBLE FLOW, DOUBLE STAGE NS = 2050 PUMPS. FOR THE SINGLE FLOW SINGLE STAGE PUMP NS = 1725 THE EXPECTED EFFICIENCY LOWER BY 0,3 0/0. FOR THE 4-STAGE-PUMP NS = 2170 LOWER BY ABOUT 1 0/0.

3.
DEPENDABILITY WITH CLEAN WATER AND ADEQUATE NEGATIVE SUCTION HEAD THE SAME WITH ALL TYPES. WITH SAND CARRYING WATER 2-STAGE PUMP MOST FAVORABLE. LESS FAVORABLE THE 4-STAGE PUMP BECAUSE OF INCREASED WEAR OF CLEARANCES FOR COMPENSATION OF HYDRAULIC THRUST. LESS FAVORABLE ALSO SINGLE STAGE PUMP BECAUSE OF WEAR OF CLEARANCES AND BLADING RESULTING FROM HIGHER STAGE DELIVERY HEAD.

4.
ACCESSIBILITY FOR INSPECTION OF THE FIRST STAGE THE SAME FOR ALL PUMPS. FOR CEMPLETE DISMANTLING THE ORDER IN RESPECT OF LEAST COMPLICATION IS SINGLE STAGE, DOUBLE STAGE, 4 STAGE. ACCESSIBILITY AND MAINTENANCE IN HORIZONTAL ARRANGEMENT FOR ALL 3 TYPES MOR FAVORABLE THAN VERTICAL ARRANGEMENT. STARTING OF 4-STAGE-PUMP IN AIR COMPLICATED AND SO FAR NOT YET CARRIED OUT.

5.
PRICES OF PUMPS WITHOUT SHUT-OFF EQUIPMENT FOUR-STAGE PUMPS 100 0/0, DOUBLE-STAGE PUMPS ABOUT 90 0/0, SINGLE-STAGE PUMPS ABOUT 65 0/0.

6.
FOR A FINAL ASSESMENT OF THE MOST FAVORABLE PUMP LIFT SYSTEM AND OF THE MOST FAVORABLE PUMP TYPE FURTHER ESSENTIAL PREREQUISITS SHOULD BE SETTLED, SUCH AS LAY-OUT OF ENTIRE A PLANT, PENSTOCK CONDITIONS, LOSSES IN CANAL AND PENSTOCKS, CAPACITY OF AN INTERMEDIATE RESERVOIR, POSSIBLE SETTING, PERMISSABLE STARTING POWER REQUIREMENTS ETC.

BRIMKAMP
714866C JMVH D

PL. READ 4.

.... ALL 3 TYPES MOR FAVORABLE THAN..+

Letter from P. Jaray, Chief Engineer, Motor-Columbus Baden, Switzerland, to A. R. Golze', July 23, 1965

Department of Water Resources Memorandum from D. P. Thayer to H. G. Dewey, Jr., and A. R. Golze', July 24, 1965

Department of Water Resources Memorandum from J. J. Doody to J. R. Teerink and A. R. Golze', July 29, 1965

Telegram from J. R. Hardin, Chairman, Tehachapi Crossing Consulting Board, to A. R. Golze', August 13, 1965

Department of Water Resources Memorandum from A. R. Golze' to W. E. Warne, August 18, 1965

Letter from J. R. Hardin, Chairman, Tehachapi Crossing Consulting Board, to A. R. Golze', September 10, 1965

P. Jaray, Chief Engineer
MOTOR-COLUMBUS BADEN

Baden, July 23, 1965

Mr. Alfred R. Golzé
Chief Engineer

Department of Water Resources

P.O. Box 388

Sacramento 2
California / USA

Dear Mr. Golzé:

I regret very much that, due to last minute postponement, I was not able to attend the DMJM Technical Advisory Board Meeting, and so I had no chance to discuss your problems with you. Meanwhile, our engineers, Mr. S. Jacobsen and Mr. O. Hartmann have informed me about the meeting and also about the site trip on July 12, 1965 together with Mr.R. Bowerman of DMJM. I appreciate very much that our engineers had a chance to get a personal impression of the site conditions and I wish to thank you and your engineers from Sacramento and from the Southern Group for arranging this visit and all the assistance extended to our people.

As indicated to you in a telephone conversation on July 13, Mr. Jacobsen and Mr. Hartmann have reported on their impression, and the information they have gathered was discussed with our civil and tunneling specialists. Summarizing this discussion, I should like to express some views on the project which might be of interest to you.

It should be kept in mind, that the civil engineering part, and as such the essential factors of judgement on the overall lift-system, is outside the present contract of DMJM, and the information we have on these items, is limited. Therefore, the following reflects the opinion of our engineers and myself to the best of our knowledge and based on the available information, and does not represent an official statement of the DMJM-MC consulting group.

1. Site of Pumping Plant

Cores of test holes show that both the Diorite and the sandstone overlay are composed of sound rock, suitable for tunneling. According to boring crew, the cores of different bore-holes in this area are very similar. This would indicate that the area has no major distortions, that a rather uniform character of the rock can be expected, and that underground work would not encounter major difficulties. Underground discharge lines and also an underground pumping station are favored by these conditions, especially if a great portion of the structures can be placed in the massif Diorite base-rock.

On the other hand, open penstocks, to be anchored on sound rock, seem to require deep cuts. We have the impression that the stability of the ridge slopes might be disturbed seriously by such cuts. Special attention should be given to the water in the ground. The slope stability would be reduced due to a lubricating effect of the water and deep cuts in the surface would require special care.

The general impression of the site conditions confirms our opinion that underground penstocks and plants are safer than surface structures. This opinion was expressed already in our "General Review", dated February 1965, at this time based on the DWR September 1964 report.

2. Reservoir for Two-Lift System

The site visit showed clearly that the terrain is very unfavorable for an intermediate reservoir. The narrow and steep gorge would allow only a very limited water storage. The steep slopes indicate the risk of mountain slides, especially in this seismic active area, with the possible consequences of overtopping and filling the reservoir with debris. Even normal surges and minor slides may result in higher sand intrusion into the pumping system. For these reasons, such a reservoir should be avoided, if ever possible.

If, however, such a reservoir must be built, we believe that a concrete gravity dam is preferable to a rockfill dam, because it provides more useful storage capacity and is safer against overtopping and earthquake.

. Operation of Multilift Schemes

t is usual practice in Europe as well as throughout the world, to ombine several plants in a "multiple" hydropower or pumping scheme. he number of plants is dictated mainly by the topography. Another oint of view is to best utilize the water inflow on various levels. oth factors do not exist for the Tehachapi Crossing: The ridge route hows a rather uniform slope of 1 : 4, which is reasonable, and the low is constant throughout the crossing.

he Schluchseewerk scheme in Germany has been cited as an example for "multilift" scheme in Europe. But here, virtually the same total head of roughly 2,000 feet is spread over a horizontal distance of 19 miles (see DMJM Interim Report, Vol. III, Page P 14) with water intakes on different levels. Similar conditions are prevailing in many other schemes, but we could not think of a single one, where a multiple lift scheme was built only to apply a certain pump or turbine type.

The operation of each plant in such multiple scheme is, of course, coordinated to achieve best economy; transients in one plant do, however, not effect the operation of the other plants, because large intermediate reservoirs are used. Within periods of hours or days, each plant can be operated independently.

The fact that intermediate reservoirs of minimum size only can be built on the Tehachapi ridge is a severe restriction to any multi-lift scheme. Transients in one plant require quick adjustment of operation in the other plants. Automatic control systems will normally take care of this, but in case of malfunction of the automatic control, the situation is generally hazardous. It is also doubtful, whether in such case the operators will act correct. Therefore, we feel that the condition of "fail safe" is not fulfilled.

The situation is even more dangerous with off-line reservoirs. The inertia of the water column in the connection line between reservoir and main discharge line leads to a considerable dead time before a balancing action is effective on the system. In other words, during a short period of time of a transient, the off-line reservoir is virtually non-existent. Obviously, this requires strict simultaneous plant operation by automatic devices, and the consequences of failure of the automatic control have to be considered. Such consequences can be: overtopping, dry-run of the pumps, excessive downsurge in the penstock of the upper station.

The probability of such events, like mountain slide into the reservoir or control failure, is certainly a very remote one. We feel, however, that realibility statistics are not applicable here in the same way as on pumping units, because eminent damage to the whole system is the possible consequence. Wear on a pump impeller for instance, and failure of a reservoir are entirely different categories of risk. While the DMJM Reliability Study shows that the combined reliability of the electrical and mechanical elements is higher in a single-lift scheme than in multilift schemes, we come to the conclusion, that the single-lift scheme is also safer, as it does not include intermediate reservoirs in difficult and seismic active terrain and the risk of major damage due to control failure.

4. Electric Motor Starting

It may be of interest to you to hear that the Z'mutt pumping plant has been commissioned recently. This plant includes two 32 MW synchronous motors, manufactured by Maschinenfabrik Oerlikon, to drive vertical Sulzer pumps at 1,500 rpm rated speed. The units are started with filled pump, reduced voltage inductive start. The rotor has 4 solid poles, no amortisseur winding. It should be noted that the power per pole, which is a significant figure for the power concentration, is considerably higher than for the Tehachapi 10-pole units: 8 MW/pole for Z'mutt and 5.5 MW/pole for Tehachapi. No problems were reported. This proves, that there are ways to accomplish self-starting motors for the Tehachapi project and there is no need to go into complications like synchronous back-to-back starting.

I hope, that these considerations are helpful to you. If there are any other problems where we could be of assistance, please feel free to call on me.

Yours very truly,

P. Jaray

P. Jaray

cc:

I.F. Mendenhall

1. Mr. H. G. Dewey, Jr.
2. Mr. Alfred R. Golze'

July 24, 1965

Tehachapi Pump
Lift System

Donald P. Thayer

Reference is made to the following:

1. My memorandum to you dated May 10, 1965, same subject, analyzing the report of the Tehachapi Crossing Consulting Board to you of May 8, 1965, and concluding with seven recommendations.

2. Letter to Mr. Golze' from Mr. R. A. Skinner, General Manager and Chief Engineer of the Metropolitan Water District, recommending adoption of the two-lift system for the Tehachapi Crossing, and transmitting two reports identified in paragraphs 3 and 4 following.

3. Report prepared by the Metropolitan Water District staff entitled "Recommendation of the Adoption of a Two-Lift System Along the Ridge Alinement for the Tehachapi Crossing of the California Aqueduct" dated July 1965.

4. Report prepared by the Bechtel Corporation entitled "Ridge Location Pump Systems, Single-Lift and Two-Lift, for the Tehachapi Crossing of the California State Water Project" dated July 1965.

I have examined the reports, references 3 and 4, in detail, both personally and in consultation with my staff and with Mr. Dewey. In this review I find that the MWD has not modified its former position, with which you are quite familiar, in any way except for the following aspects:

1. They have abandoned the Pastoria Creek alignment and now favor construction of the Tehachapi Lift along the Ridge Route.

2. They recommend that the two-stage double flow pump with horizontal shaft be adopted for the two-lift system.

In view of the foregoing, I see no reason to change my recommendations made to you previously in my memorandum referenced 1. above, except that I now wish to withdraw my former recommendation that consideration be given to a five-stage pump; I believe that there is now no reason to pursue this matter further. With your partial approval previously transmitted to me, my recommendations number 2, 3, and 7 are now being acted upon.

With reference to my previous recommendation number 2., the alignment of Tunnels No. 2 and No. 3, as well as the design of Siphon No. 2 connecting them, is being studied under my direction in the Southern District office. Progress of this work was discussed with you in the Southern District office on July 9, 1965. I will be able to present a firm preliminary design for your approval on or before August 20, 1965.

With respect to my former recommendation number 3., design studies of the underground and surface discharge lines, as well as the branch connections at the pumping plant, are now under way in this office. I will be able to present a definite recommendation for your approval on or before August 20, 1965.

With respect to my former recommendation number 7., the detailed report of the studies of the Tehachapi Pump Lift System has been compiled to date, and portions forwarded to the State Printing Plant. This will be supplemented by the Daniel, Mann, Johnson and Mendenhall report presented at their Technical Advisory Board meeting on July 8 and 9, 1965, and such other subsequently developed material as is appropriate.

I now reiterate, with some amplification, my three remaining former recommendations:

1. That the single-lift plan generally along the Ridge Route be adopted for the Tehachapi Pump Lift and that final design in all phases, including preparation of pump specifications, be initiated immediately.

2. That the present model testing program be continued to conclusion with special emphasis on the model of the four-stage pump, which will be utilized for the single-lift plan, and that the Daniel, Mann, Johnson and Mendenhall program be realigned accordingly pursuant to the instructions as contained in your memorandum of April 19, 1965.

3. That the design of the approach channel and forebay for the Tehachapi Pumping Plant be completed and the work placed under contract at the earliest possible date.

APPROVED:

Alfred R. Golzé
Chief Engineer

Date: AUG 17 1965

DPThayer:cp

ite of California

The Resources Agency

Memorandum

: 1. Mr. J. R. Teerink
2. Mr. A. R. Golze'

Date : July 29, 1965

File No.:

James J. Doody
District Engineer
Southern District

Subject: Metropolitan Water District and Bechtel Corporation Reports Dated July 1965 Recommending A Two-Lift Tehachapi Pumping Plant System

m : Department of Water Resources

In accordance with your verbal instruction, the District has reviewed a report issued by the Bechtel Corporation on July 16, 1965, entitled "Report on Ridge Location Pump Systems - Single-Lift and Two-Lift for the Tehachapi Crossing of the California State Water Project", and a companion report by the Metropolitan Water District dated July 1965, entitled "Recommendation of the Adoption of a Two-Lift System Along the Ridge Alinement for the Tehachapi Crossing of the California Aqueduct". The chief points which have been made by both the Metropolitan Water District and the Bechtel Corporation in support of their recommendations for a two-lift pumping plant system are listed following together with the District's comments with respect to these points:

1. System Dependability (Reliability)

It appears that MWD and Bechtel consider the two-lift system as a whole to be no less dependable than the single-lift and, by inference, to be probably more so since "the two-lift utilizes components which have the most extensive record as far as operation is concerned, and will permit the construction of the most reliable and dependable system without using equipment and methods not fully developed to date".

District Comments

Our opinion is that the two-lift is not as dependable as the single-lift for these reasons:

A. Two stations in series have reliability equal to the reliability of each station multiplied together, or a lower reliability than a single-lift plant. This is thoroughly treated in DMJM's "Tehachapi Research and Development Program Interim Report" dated April 1965, Volume II, Part A, Chapter 7. With a higher outage time for preventive maintenance of the single-lift pumps taken into account, the single-lift plant is shown to have a significant advantage in reliability over the two-lift plant.

B. The MWD/Bechtel challenge of the DMJM conclusions will require a more systematic presentation by MWD before it can be evaluated properly.

JUL 29 1965

RNAME (REV. 4-62)	Doody	AUG 1 1965		

2. Foundations for Plant

The foundation for the valley pump house is not as sound as that for the uphill pump house of the two-lift plant. Therefore, the chief danger due to seismic disturbances is to the entire single-lift plant, but to only one-half of the two-lift plant.

District Comments

Our geologic exploration of the foundation for the single plant indicates that the plant would be founded on materials of lesser strength than the materials which would comprise the foundation of a second plant of a dual-lift system. In this respect, the contention of the Metropolitan Water District and the Bechtel Corporation is correct. However, a properly designed pumping station, as would be required for a single-lift system, can be made to withstand all anticipated seismic forces. Further, the contention of MWD and Bechtel is really not valid inasmuch as a two-lift system still requires a single plant on the floor of the valley which would be subject to the same seismic forces.

3. Discharge Lines

The lower half of the discharge lines for the single-lift (being subject to the higher pressures compared to those acting on the two-lift lines) involves greater hazards. Should the lines be broken by the displacements or shocks created during an earthquake, greater damage would be inflicted by the higher velocity (higher head) flows. Also, the higher pressures create greater difficulties in the field assembly of the thicker pipe sections which make the lines more susceptible to flows in the circumferential welds. Therefore, the two-lift discharge lines are inherently safer than the single-lift lines.

District Comments

The contention made by MWD and Bechtel is essentially correct. The pressures would be higher for a single-lift system than for a two-lift system, and there are greater problems involved in welding thicker steel required for the higher heads in the penstocks. However, it is generally agreed that high-strength steels properly controlled can be welded to withstand the pressures involved. It is certain that special precautions will have to be exercised, such as the extraction of moisture from the area in which the weld is being made; also, extraction of moisture from the metals being welded as well as the welding rod; and, further, highly specialized welders would be required. It is understood that this is costly and that a high degree of control must be exercised. However, there is no reason in our opinion why this cannot be done.

In respect to damage which might be inflicted by escaping water, although this would be initially true for a single-lift plant, the volume of water would rapidly diminish to a point where only nominal damage would be inflicted on the facilities below the point of rupture.

4. Pumps

The pumps for the two-lift have a greater record of satisfactory operation at the given head and capacity as compared to those for the single-lift. Therefore, they are better for lifting the plant flow.

District Comments

The reliability of four-stage pumps has been shown to be high by DMJM in their interim report of April 1965, Volume II, Part A, Chapter 7. In addition, Chapter 2, Part A, describes the study and survey of existing single-suction multistage pumps; and Chapter 3 covers the pump design studies made to determine the reliability to be expected. These careful and comprehensive investigations give the strongest assurance that the four-stage pumps will have the high reliability predicted for them.

A predicted prototype efficiency for the four-stage single-suction and the two-stage double-flow pumps of 91.2 and 92.4 percent, respectively, was determined on the basis of the model test described in Chapter 1, Part A, of the above-mentioned report.

5. Motors

The starting of the motors for the two-lift pumps will be less of a problem since the pump casings can be dewatered to reduce the starting load. There is no precedent for starting pumps of three or more stages with cases dewatered.

District Comments

In the case of three or more staged pumps, it is true that there is no precedent for starting pumps with cases dewatered.

6. Operating Controls

The dependability and reliability of the single- and two-lift systems will be essentially the same insofar as controls are concerned. The two-lift system will use redundant controls and "will not decrease the reliability if a proper maintenance program is scheduled".

District Comments

The reliability of the operating controls for the two-lift system will not be as high as those for the single-lift regardless of the care taken in preventive maintenance and the additional redundancy that may be used. This is so because there are the additional controls required by the two-lift stations in order to integrate their operations. The degree to which the two-lift is less reliable on account of the more complicated controls is covered in detail in Appendix E-1, "Electrical Control System", of the Department's "Preliminary Report of Technical and Economic Feasibility of Single-Lift, Two-Lift, and Three-Lift Systems - Tehachapi Pumping Plant", dated September 1964.

7. Project Costs

"The capital cost of the two-lift system is considered to be equal to that of a single-lift system within the accuracy of the estimates." The power and energy costs for the two-lift will be less than that for the single-lift "because of the 2.5 percent better efficiency of the two-stage DF pumps. Including the operations, maintenance and repair costs, the total annual cost at ultimate capacity of the two-lift will be 27.7 million dollars, and those for the single-lift will be 27.5 million dollars."

District Comments

Both Bechtel and the Department of Water Resources show that there is a capital cost differential in favor of the single-lift system in comparison with the double-lift system. The Department of Water Resources shows this to be in the vicinity of $7,100,000 and Bechtel estimates it to be approximately $8,600,000. Insofar as annual costs are concerned, the Department of Water Resources estimates indicate a difference of $40,000 annual costs in favor of the two-lift system whereas Bechtel Corporation finds an annual cost difference of approximately $200,000 in favor of the two-lift system. This difference in annual cost between the two estimates is based almost entirely on the higher power rates used by Bechtel. A general analysis of costs leads us to believe that the Bechtel report is in essential agreement with our analysis.

Since the publication of the District's latest report on the Tehachapi lift system in April 1965, considerable geologic data have been accumulated with respect to the off-line reservoir envisioned for a two-lift system on the Ridge Alignment. These data substantiate the District's previous cost estimates for a system utilizing this reservoir. Further, we have no reason to modify our original cost estimates which were presented in the aforementioned report. In view of this, the District reiterates its original recommendations with regard to the Tehachapi lift.

cc: Mr. A. Hunter
Mr. R. A. Burks

The following is the text of a Western Union telegram from General John R. Hardin to Alfred R. Golze', in response to an inquiry concerning views of the Tehachapi Crossing Consulting Board on the July 1965 reports of Bechtel Corporation and The Metropolitan Water District of Southern California:

"403P PDT AUG 13 65 OA617 PD420
P LLB368 PD DDX ST MICHAELS MD 13 605P EDTNIR GOLZE
CHIEF ENGINEER DEPT OF WATER RESOURCES SACRAMENTO CALIF
RE LET AUG 10 FROM J A WINELAND AND REPORTS OF M W D AND BECHTEL:
IT IS OUR CONSENSUS OF OUR BOARD THAT THE MATERIAL FURNISHED
DOES NOT CHANGE OUR PREVIOUS RECOMMENDATION AS SET FORTH IN
OUR REPORT MAY 8TH 1965 LACK OF KNOWLEDGE OF D M J M RECENT
FINDINGS, IF ANY, ON PUMP AND SYSTEMS EFFICIENCIES HAS HANDICAPPED
OUR EVALUATION OF MATERIALS SUBMITTED. PARMAKIAN COULD NOT
BE CONTACTED
JOHN R. HARDIN CHAIRMAN T C C B
(52)."

State of California

The Resources Agency of California

Memorandum

To : Mr. William E. Warne, Director
Department of Water Resources

Date : August 18, 1965

File No.:

Subject : Tehachapi Pump Lift System

Alfred R. Golze'
Chief Engineer

From : Department of Water Resources

The 4,100 cfs of water in the California Aqueduct enroute to Southern California must be pumped 2,000 feet to cross the Tehachapi Mountains. Engineers working on this problem over the years have considered building a lift system using three pumping plants up the mountain side; a two-lift system with two plants; or a single-lift system with one pumping plant at the base of the mountains.

This is to advise you that I have approved the final recommendation of the engineers of the Department of Water Resources that, to provide the most dependable pumping lift at the Tehachapi, a single-lift plan be adopted. The single-lift scheme is shown by the tests and studies made, to be the most reliable and safest of the several systems studied. It is also the cheapest, by approximately $7,000,000 under the nearest competitive two-lift system. It has the unanimous support of all of the Department's technical consultants.

Supporting my decision is a lengthy history of an epic study, unprecedented in American pump-lift design. It is set forth in this memorandum, and it includes a report of the companion technical studies of the Metropolitan Water District of Southern California. The reference and supporting papers and documents are being assembled and will be reprinted as a Department of Water Resources Bulletin No. 164.

For fifteen years engineers of the Department of Water Resources, hereinafter referred to as the Department, have been studying the economic and engineering feasibility of various aqueduct alignments for transporting Northern California water into Southern California.

In February 1955 the Water Project Authority of the State transmitted to the Legislature a report[1/] prepared by the State Engineer detailing a program for constructing the Feather River Project. The Legislature (Joint Committee on Water Problems) retained the Bechtel Corporation to review the State's proposed plans and program. The Bechtel Corporation reported to the Legislature under date of December 31, 1955.[2/] In its review Bechtel Corporation endorsed the concept of a single-lift at the Tehachapi.

In October 1958 the Department published a preliminary report[3/] on a possible pumped storage power development at the Tehachapi. A single-lift of 2,550 feet was proposed using twelve five-stage pumps of 416 cubic feet per second capacity. This report was also reviewed by the Bechtel Corporation. In its review report of September 1959 to the Department[4/] Bechtel suggested reducing the number of pump

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Note: All footnotes are listed on Attachment I at the end of this memorandum.

units to eight and increasing the capacity of each to 625 cfs, retaining the single-lift arrangement.

With the publication of Bulletin No. 78[5/] in December 1959 the aqueduct alignment was finalized to go down the west side of the San Joaquin Valley and over the Tehachapi Mountains east of Grapevine (Highway 99) through an area known locally as Pastoria Creek Canyon. A single-lift pumping plant of about 2,000 feet was included in the plans to reach the proper crossing elevation (3,100 feet above sea level). Bulletin No. 78 was reviewed by and received the general approval of a Board of Consultants of which Ralph A. Tudor was chairman.[6/] In its report the consultants supported the single-lift proposal but stated:

> "We wish to express strongly our opinion that in the future, prior to final design, complete studies and comparisons must be made of all reasonable schemes of pumping and power recovery."

The Burns-Porter Act passed by the State Legislature and approved by Governor Brown in 1959[7/] authorizes the State Water Project. With reference to the Tehachapi Crossing of the Project this Act provides in Sections 12931 and 12934(d)(2) of the State Water Code for construction of the State Water Facilities which are defined to include "a San Joaquin Valley-Southern California aqueduct extending to termini in the vicinity of Newhall, Los Angeles County". Also Section 11260 of the Water Code by amendment in 1959 authorizes the facilities recommended in Bulletin No. 78.

Following a ratifying vote of the people of the State in 1960, which endorsed bond financing of the new State Water Project, detailed engineering and economic studies of the Tehachapi Crossing were undertaken by the state engineers in Southern District of the Department of Water Resources in Los Angeles. As these studies progressed it became apparent that there were two possible alignments for the pump lift at the Tehachapi, one up Pastoria Creek Canyon and the other up a rocky ridge called the Ridge Route about a mile east of Pastoria Creek Canyon. Three possible lift arrangements were selected for a complete engineering analysis on these alignments: a single-lift of 2,000 feet; a two-lift of 1,000 feet each; and a three-lift scheme of about 670 feet each.

Because of the lack of experience in the United States with high head pumping plants, the Department of Water Resources, as part of its engineering program for the Tehachapi Crossing, in 1963 entered into a contract[8/] with Daniel, Mann, Johnson and Mendenhall of Los Angeles, in association with Motor-Colombus of Baden, Switzerland, (hereinafter referred to as DMJM) for a research and pump model testing program. This program is to determine and analyze the feasibility, reliability and efficiency factors for each lift system. Major emphasis is placed on a model analysis of a single-stage pump to serve in a three-lift system, a two-stage pump to serve in a two-lift system and a four-stage pump to serve in a single-lift system. The two-stage and four-stage pump models were built and are being tested by European firms (Voith of Heidenhem, Germany and Sulzer Brothers of Wintherthur, Switzerland) with long experience in high head pump design and manufacture. A single-stage pump model is undergoing tests in the plant of the Byron Jackson Company in Los Angeles.

In February of this year a recommendation from Donald P. Thayer, Deputy Division Engineer of the Division of Design and Construction, was approved by me to make no further investigation of the three-lift system, for sound engineering reasons.[9/] The alignments then placed under final study were for (1) a system of works up Pastoria Creek Canyon, and (2) up the Ridge Route. Six schemes were given final consideration -- 3 two-lift schemes and 3 single-lift schemes with 3 each in Pastoria Creek Canyon and on the Ridge Route.

In April 1965 the engineers of the Department completed and submitted to me their report of the investigation of the six schemes.[10/] In this report the department engineers recommended:

> "Proceed immediately with design of a system along the Ridge Route (System 4, Ridge Two-Lift, System 5, Ridge Single-Lift with underground penstocks, or System 6, Ridge Single-Lift with surface penstocks)."

A companion report[11/] also dated April 1965 and dealing with the Department's model test program on pumps for the Tehachapi was submitted to me by our consultants, DMJM. This extensive report in four volumes examined in detail the operating experience in Europe and reported on the results of the model tests then under way. It concluded:

> "Regardless of the pump type selected ... there is no doubt whatever that the pump industry will be able to design and build pumps for Tehachapi that will be reliable and will give satisfactory service over the next 50 years."

My trip to Europe in April 1965 permitted me to discuss high head pump design with European engineers working on the models of the Tehachapi pumps and to visit plants with multistage pumps operating under heads exceeding 3,000 feet (such as Lunersee, Austria). My impressions are summarized in my trip report to you[12/] and Donald P. Thayer's companion report to me and the Director.[13/] Based on this European experience I concur in the general statement of our consultants, DMJM, quoted above.

Early in April 1965, the Department's distinguished Consulting Board for Earthquake Analysis[14/] was convened to review the seismic situation at Pastoria Creek Canyon and the Ridge Route. In its report to me of April 8, 1965,[15/] this Board expressed its view that, "The Ridge scheme is preferable to the Canyon scheme in that it is less vulnerable to damage and presents less potential hazard to life and property".

On May 3, 1965, the Department's Tehachapi Crossing Consulting Board[16/] assembled in Bakersfield for a field trip over the Pastoria Creek Canyon and Ridge Route alignment and plant sites. The balance of the week was spent by the Board in Sacramento. On May 5 the Bechtel Corporation as consultants for the Metropolitan Water District of Southern California (hereinafter referred to as MWD) presented to the Tehachapi Crossing Consulting Board their findings: (1) on the lift concept, and (2) of the pump studies being made for them at East Kilbride, Scotland. The Bechtel Corporation accepted the Pastoria Creek Canyon Route as infeasible geologically and recommended that pump selection be deferred pending further model testing of single-stage pumps for a 1,000-foot head. Robert Skinner, Chief Engineer and General Manager, speaking for MWD, generally supported the Bechtel Corporation findings with the added statement that he considered the single-lift concept to be the least optimum of the several choices available. The reports and documents presented by the Bechtel Corporation, MWD and their consultants at the May 5 meeting are being published by the Department as Book I of Bulletin No. 164.

Department engineers and DMJM engineers made separate presentations to the Board on May 6. Their presentations showed that the Ridge Route was the most feasible one. They showed clearly that either the single-lift or two-lift scheme could be built but there were important engineering and geological factors to be considered for each lift. The department presentation was based on its report of April 1965[10/] and DMJM used its April report to the Department.[11/]

The Tehachapi Crossing Consulting Board studied the presentations in depth. It submitted a report to me under date of May 8.[17/] Its report is of major significance to me in reaching a conclusion on the proper course of action. The Tehachapi Crossing Consulting Board in its report first finds that, "No further consideration of the Pastoria Canyon routes is warranted ... since the recent site explorations adequately support this conclusion."

The Tehachapi Crossing Consulting Board then considered the geology and seismology of the area. With respect to geology its report states:

> "In general, the overall site geology in the Ridge area is favorable and reasonably good rock is found at relatively shallow depths. . . . The effect of geology is largely a function of the number of structures, surficial or underground features, and the actual specific location of structures, particularly on the surface .... Considering the foregoing, it is obvious that the two-lift scheme has over twice the number of exposed surficial structures .... Hence, the geology is more favorable to the single-lift scheme."

With respect to seismology the Board's report states:

> "Here again the location of the structures and the number of structures are important. The two-lift scheme, having over twice the number of structures, offers twice the chance for seismic damage. . . . The one-lift Ridge alignment, with underground discharge lines, has only the one pumping plant located on the surface and most of the conveyance system is underground where, in the best rock of the area, the effects of shaking will be minimized. Hence, with regards to seismic hazard, the single-lift Ridge scheme with underground discharge lines has a marked superiority."

The Tehachapi Crossing Consulting Board, in its May 8, 1965, report further states:

> "In all of the presentations and reviews, emphasis has been placed on the need to select a lift scheme which will offer maximum dependability and reliability. The Board fully concurs with this objective and, in summary, has evaluated the several basic elements of the Ridge single-lift scheme in this reference as follows:
>
> "Four-stage, single-lift pumps are no more complicated than two-stage, double-flow pumps and are fully as capable of being ruggedly constructed and reliably operated.

"Single-lift discharge lines can be as reliably designed and constructed to give safe service as any other system by utilizing high quality steels and conservatively sizing the manifolds and branches.

"Controls for the single-lift will be least extensive and least complicated and therefore the most reliable.

"Power transmission, transformer and switchyard facilities will serve a single location and therefore will be least exposed to outages.

"Water storage for the single-lift requires only a single forebay and at least halves the problems and hazards of reservoir operation.

"Personnel for the single-lift requires minimum use of personnel for surveillance and operation, thus minimizing opportunity for human errors in operation.

"The single-lift provides maximum simplicity of layout, and offers least opportunity for misoperation. This is judged to be of special importance in relation to coordination with the operation of the several upstream pumping stations and the several downstream pump and generating plants, all of which will operate in series with the Tehachapi lift."

In its unanimous recommendation, the Board concluded:

"It is the sense of the Board's collective judgment that the Department can now undertake with confidence the final design of a single-lift scheme along the Ridge alignment."

On May 20, 1965, subsequent to receipt of the Tehachapi Crossing Consulting Board's report, the Engineering and Operations Committee of MWD's Board of Directors convened in special session in Los Angeles for an oral and chart presentation by me and department and DMJM engineers of the Department's and DMJM's engineering findings supporting selection of the single-lift concept. At the conclusion of this meeting, I pointed out to the MWD Engineering

Committee that in the absence of compelling technical support to the contrary I would have no basis on which to reject the recommendations of the state engineers and the State's consultants. The MWD Committee asked that my final decision be delayed until MWD staff and Bechtel Corporation staff could prepare and submit to the MWD Board at its July 13, 1965, meeting their final technical recommendations to be forwarded to me immediately thereafter. This I agreed to, reluctantly, in view of the adverse impact on our construction schedule for the Crossing.

On May 26, 1965, in response to an invitation from the MWD Engineering Committee, DMJM made a more detailed oral and chart presentation to it, concentrating on details of the model pump test program.

To be of assistance to MWD and to be responsive to their concern, DMJM prepared for the Department a supplement to its April 1965 report, discussing in detail the factors supporting the single-lift concept, in particular, the design and operation of multistage pumps. This report[18/] was made available to MWD, Bechtel Corporation and DWR staff at a meeting of the Technical Advisory Board[19/] of DMJM held in Los Angeles on July 8 and 9, 1965.

At the July meeting, the Technical Advisory Board of DMJM, considered all questions previously raised by MWD on the single-lift system dealing primarily with the pumps -- their design and operating experience. The European consultants to the Department and DMJM and American manufacturers reported at the July meeting on the strengths and weaknesses of the single-lift system. Robert Skinner, Chief Engineer and General Manager of MWD attended these sessions, accompanied by MWD staff and Bechtel Corporation representatives. The report of the Technical Advisory Board[20/] was transmitted to me on July 9, 1965, with copies to MWD and Bechtel Corporation. This Board concludes:

> "Previous reports and studies have found the single-lift system to be the best choice for the Tehachapi Crossing because of its simplicity and overall reliability as compared to multi-lift concepts. Based on these studies and our own review and analysis of specialized aspects of the problems, the Technical Advisory Board endorses the choice of the single-lift system."

At the meeting of the full MWD Board on July 13, 1965, Robert Skinner submitted to it the Bechtel Corporation Report of July 1965[21/] and an unnumbered MWD report of July 1965.[22/] The Bechtel Corporation report recommends a two-lift system with underground discharge lines using two-stage, double flow horizontal pumps. The MWD July report, page 33, concurs with the Bechtel report recommendation for a two-lift system adding however, the following significant comment:

> "Nothing has been presented which precludes the use of a single-lift system on the ridge alignment; however, the pumps for such a system are less efficient than those for a two-lift system and the penstocks require excessive plate thickness."

The European model tests conducted by DMJM indicate that the double flow, two-stage pumps are about one percent more efficient than the four-stage, single-flow pump proposed for the single-lift. This pump advantage disappears when considering the efficiency of the overall system from the lower forebay to the portal of tunnel at elevation 3,100. The Bechtel Corporation July 1965 report, p. V-9, commented:

> "It should be noted that the ... present worth of operating cost ... differentials (of less than one percent) are based upon the originally assumed pump efficiencies, rather than those indicated by recent preliminary tests. If final tests verify present indications, the differences in present worth of total cost shown by ... this comparison ... would be virtually eliminated, making the present worth of total costs approximately equal for all systems."

The single-lift will require penstock steel of greater thickness than the two-lift but not beyond current practice or capability of the steel industry to manufacture and install.

Mr. Skinner transmitted the Bechtel Corporation and MWD July reports to me by his letter of July 19, 1965.[23/] Mr. Skinner asked that I give careful consideration to the recommendations contained in the two reports.

The July 1965 reports of Bechtel Corporation and MWD have been reviewed by the Tehachapi Crossing Consulting Board. General Hardin, Chairman of the Board has advised me[24/] his Board finds no basis for any change in its recommendations to me of May 8, 1965.

Assisting the Department in this study of the Tehachapi Crossing have been a number of distinguished consulting engineers, geologists and seismologists, both American and European. Their views and findings appear in the various reports and letters to which reference is made herein. Without exception these consultants endorse the single-lift system as the proper one to be built at the Tehachapis.

Supplementing the formal reports, a letter[25] of comment on the crossing problems has been received under date of July 23, 1965, from P. Jaray, Chief Engineer of the consulting engineer firm of Motor-Columbus, Baden, Switzerland. Motor-Columbus is an associate of DMJM on its Tehachapi studies for the Department. Motor-Columbus has an extensive engineering experience with high head pumping plants in Europe and elsewhere in the world. Chief Engineer Jaray's views are summarized in his statement that:

> "While the DMJM Reliability study shows that the combined reliability of the electrical and mechanical elements is higher in a single-lift scheme than in multi-lift schemes, we come to the conclusion, that the single-lift scheme is also safer, as it does not include intermediate reservoirs in difficult and seismic active terrain and the risk of major damage due to control failure."

The recommendations of department staff are found in three staff memoranda addressed to me. They are Mr. Thayer's memorandum of May 10, 1965,[26] Mr. Thayer's memorandum of July 24, 1965,[27] and Mr. J. J. Doody's memorandum of July 29, 1965.[28] These memoranda, on the basis of the facts presented, recommend adoption of the single-lift system for the Tehachapi pump lift. Mr. Thayer withholds for later submission his recommendation as to whether the penstocks should be surface or underground.

The situation therefore to be resolved is whether the recommendation of MWD, the Bechtel Corporation and its consultants for a two-lift system at the Tehachapi, which incidentally conflicts with Bechtel's earlier support of the single-lift concept, should prevail over the recommendation of department staff, the Tehachapi

Crossing Board, DMJM and its consultants that the single-lift concept should be adopted.

I have carefully read the reports and memoranda cited herein, including the July reports of MWD and Bechtel Corporation, and I have arranged for their publication in Department's Bulletin No. 164 or for deposit in the library of the Resources Agency in Sacramento. I have attended meetings of the Boards of the Department's consultants. I have inspected the lift sites in the field on several occasions and have inspected operation of prototypes in Europe.

It is the objective of the Department to provide the most dependable pump lift system at the Tehachapi. The best interests of the water users and the Department demand it. It is clear that the most dependable system is that which has the greatest reliability and is the safest. The single-lift system is demonstrated by the factual data in the referenced support material to exceed the two-lift in both reliability and safety. It is also the cheapest, approximately $7,000,000 less than the two-lift system.

This review and analysis has convinced me that there is no substantial technical basis to require me to disregard or reverse the recommendations of the department engineers and its consultants. Accordingly, I have approved Mr. Thayer's recommendations and instructed him to proceed forthwith with the implementation of the single-lift pumping concept at the Tehachapi using four-stage, single-flow pumps and to expedite his recommendation on the type of penstock construction to be adopted.

Attachment

Attachment I

Tehachapi Crossing

Report of Chief Engineer to Director
Department of Water Resources

REFERENCE NOTES

(Items marked (*) are included in Department of Water Resources Bulletin No. 164. All other publications are available in the Library of the Resources Agency, Sacramento, California, or the offices of the Department of Water Resources in Los Angeles.)

1. Program for Financing and Constructing the Feather River Project as the Initial Unit of the California Water Plan, prepared by the State Engineer and transmitted to the Legislature by the State Water Project Authority, February 18, 1955.

2. Report on the Engineering, Economic and Financial Aspects of the Feather River Project to the Joint Committee on Water Problems, California State Legislature, Bechtel Corporation, December 31, 1955.

3. Preliminary Report on Tehachapi Pumped Storage Power Development, Department of Water Resources, October 1958.

4. Review of Preliminary Report on Tehachapi Pumped Storage Power Development for State of California, Department of Water Resources, Bechtel Corporation, September 1959.

5. Investigation of Alternative Aqueduct Systems to serve Southern California, Bulletin No. 78, Department of Water Resources, December 1959.

6. Report to Director - Department of Water Resources, State of California by Board of Consultants on Alternative Aqueduct Systems to Serve Southern California, September 1959. This report is bound in front of Bulletin 78, reference No. 5 above. Cited quotation appears on page 25 of Bulletin 78.

7. The California Water Resources Development Bond Act, approved by the voters of the State on November 8, 1960, now Water Code Sections 12930-12944, popularly referred to as the "Burns-Porter Act" after its authors, Senator Hugh M. Burns and Assemblyman Carley V. Porter. The Water Code is available in book form.

*8. State of California, Department of Water Resources, Tehachapi Pumping Plant, Research and Development Program, Contract No. 352872 with Daniel, Mann, Johnson and Mendenhall, Los Angeles, California.

*9. Memorandum - Alfred R. Golze' to J. J. Doody - January 15, 1965
Memorandum - J. J. Doody to J. M. Haley and A. R. Golze - January 29, 1965
Memorandum - Donald P. Thayer to H. G. Dewey, Jr. and A. R. Golze' - February 10, 1965 - Approved by the Chief Engineer on February 11, 1965

Note: Subject on all of above memoranda: Tehachapi Crossing

*10. Report on Alternative Locations of Tehachapi Lift System, Department of Water Resources, unnumbered publication, April, 1965.

*11. Tehachapi Pumping Facility, California State Water Project Reports on Research and Development Program by Daniel, Mann, Johnson and Mendenhall, April 1965:

Volume I, Comparative Analysis
Volume II, Technical Studies - Parts A and B
Volume III, Investigation of high head pumping practice in Europe and the United States
Volume IV, Program Management

*12. Memorandum - Alfred R. Golze' to William E. Warne, April 23, 1965, Subject: Tehachapi Crossing, European Trip, April 3-16, inclusive.

*13. Memorandum - Donald P. Thayer to Alfred R. Golze' and William E. Warne, April 28, 1965, Subject: Tehachapi Crossing, European Trip, April 3-16, inclusive.

14. Consulting Board for Earthquake Analysis - Department of Water Resources.

CHAIRMAN

Dr. Hugo Benioff

Dr. Benioff is a consulting seismologist, was a professor of seismology at the California Institute of Technology for over 30 years and is internationally recognized as an authority on seismic phenomena and instrumentation.

MEMBERS

Dr. George Housner

Dr. Housner is a structural engineer specializing in earthquake design, a professor at the California Institute of Technology and chairman of the Earthquake Research Institute which is well known for its research in earthquake problems relating to civil engineering.

Dr. Clarence Allen

Dr. Allen is a consulting geologist, a noted authority on earthquake faulting and head of the Seismological Laboratory of the California Institute of Technology.

Dr. H. Bolton Seed

Dr. Seed is a recognized authority on soil mechanics, a professor at the University of California at Berkeley and is well known for his model experiments of dams and embankments using simulated earthquake forces.

Mr. N. D. Whitman, Jr.

Mr. Whitman is a consulting engineer specializing in hydraulic structures and a graduate of the California Institute of Technology with over 30 years of experience including participation in design of structures such as the San Francisco Bay Bridge.

Dr. James L. Sherard

Dr. Sherard is vice president of the consulting firm of Woodward, Clyde, Sherard and Associates, a graduate of the University of California, Berkeley and Harvard in civil engineering and soil mechanics, and is an international authority on embankment type dams.

*15. Letter report - from the Consulting Board for Earthquake Analysis to Alfred R. Golze' - dated April 8, 1965, at Los Angeles, California - signed by all members of Board.

16. Tehachapi Crossing Consulting Board - Department of Water Resources.

CHAIRMAN

John R. Hardin

Retired from the U. S. Army in 1957 with the rank of Major General. During his Army career, General Hardin served as Assistant Chief Engineer of Military Construction, and was President of the Mississippi River Commission. He is a registered civil engineer in California.

MEMBERS

R. C. Hornberger

A principal engineer with Svedrup and Parcel and Associates, Inc., engaged in electrical power studies and design of special structures. He is a registered civil engineer in California.

Thomas M. Leps

A consulting engineer specializing in the field of soil mechanics and foundation engineering. As Chief Civil Engineer of Southern California Edison Company he supervised the design of a wide variety of hydroelectric projects. He is a registered civil engineer in California.

Elmer C. Marliave

A consulting geologist. He has performed services for numerous construction firms in the U.S.A. and abroad.

Robert Sailer

Retired from the U. S. Bureau of Reclamation after 28 years where he was in charge of pressure conduits for several projects. He has wide experience in the design of major pipelines, large pipe siphons, and large pump discharge lines.

John Parmakian

Retired after 33 years of service with the U. S. Bureau of Reclamation. At the time of his retirement he was Associate Chief Engineer. His major field is the analysis and design of hydraulic machinery. He is a registered professional engineer in California.

Louis G. Puls

Retired from the U. S. Bureau of Reclamation as Chief Design Engineer. His experience with the Bureau covered many years of experience with all types of dams. He is a registered professional engineer in California.

*17. Letter report - from the Tehachapi Crossing Consulting Board to Alfred R. Golze' - dated May 8, 1965, signed by all members of the Board except Louis G. Puls, necessarily absent.

*18. Considerations Relating to a Single Lift for the Tehachapi Crossing - Daniel, Mann, Johnson, and Mendenhall for the Department of Water Resources, July 1965.

19. Technical Advisory Board - Daniel, Mann, Johnson, Mendenhall.

CHAIRMAN

Irvan F. Mendenhall

Civil Engineer, Registered Professional Engineer in California. President, Daniel, Mann, Johnson, Mendenhall, Los Angeles.

MEMBERS

John T. Clabby

System Engineer and Vice President, Daniel, Mann, Johnson, Mendenhall, Los Angeles. Directs system engineering activities of DMJM including operations research and introduction of advanced defense technologies to civilian works.

S. Logan Kerr

Consulting Engineer, specializing in hydraulic machinery and investigation of water hammer since 1945, and actively engaged in design and construction of hydraulic machinery installation in the United States for the prior 20 years.

Leslie Hooper

Professor and Director of Alden Laboratory, Worcester Polytechnic Institute, Massachusetts, since 1952; formerly Freeman scholar, and engaged in hydraulic laboratory practice since 1928.

Austin H. Church

Professor of mechanical engineering, New York University since 1940, specializing in design of turbines and investigation of vibrational problems.

Peter Jaray

Chief Engineer, Motor-Columbus, Baden, Switzerland (represented by Otto Hartman at meetings in United States).

David R. Miller (Secretary)

Registered Professional Engineer in California. Vice President, Daniel, Mann, Johnson and Mendenhall in charge of large public works programs of the company.

*20. Letter report of Technical Advisory Board - from Irvan F. Mendenhall, President of Daniel, Mann, Johnson and Mendenhall and Chairman of the Technical Advisory Board to Alfred R. Golze' - dated July 9, 1965.

*21. Report on Ridge Location Pump Systems, Single Lift and Two-Lift for the Tehachapi Crossing of the California State Water Project for the Metropolitan Water District of Southern California - The Bechtel Corporation, July 1965.

*22. Recommendation of the Adoption of a Two-Lift System Along the Ridge Alinement for the Tehachapi Crossing of the California Aqueduct. The Metropolitan Water District of Southern California - an unnumbered report - July 1965.

*23. Letter - R. A. Skinner, General Manager and Chief Engineer, The Metropolitan Water District of Southern California to Alfred R. Golze' - Los Angeles, California, July 19, 1965.

*24. Telegram - General John R. Hardin to Alfred R. Golze', August 13, 1965 (responding to inquiry concerning views of Tehachapi Crossing Consulting Board on July 1965 reports of Bechtel Corporation and MWD).

*25. Letter - P. Jaray, Chief Engineer, Motor-Columbus, Baden, Switzerland to Alfred R. Golze', Baden, July 23, 1965.

*26. Memorandum - Donald P. Thayer to Alfred R. Golze', Subject: Tehachapi Pump Lift System - May 10, 1965.

*27. Memorandum - Donald P. Thayer to Alfred R. Golze', Subject: Tehachapi Pump Lift System - July 24, 1965.

*28. Memorandum - J. J. Doody to J. R. Teerink and A. R. Golze', Subject: Metropolitan Water District and Bechtel Corporation Reports, dated July 1965, recommending a Two-Lift Tehachapi Pumping Plant System, July 29, 1965.

Honorable Edmund G. Brown
Governor of California
State Capitol
Sacramento, California

August 17, 1965

Tehachapi Crossing-
State Water Project

Engineers of the Department of Water Resources have been working a long time on a solution for the pumping lift problem at the Tehachapi Mountains, which the California Aqueduct must cross to take water into Southern California.

The studies began back in the early 1950's and have been intensified the last few years preparatory to final design of the complex of pumps, penstocks, and tunnels.

The Department has employed two consulting boards, to advise staff engineers, and the Daniel, Mann, Johnson and Mendenhall Company of Los Angeles to make pump model studies. Experienced, expert engineers both in the United States and in Europe have participated in this research program. The results of this extensive engineering activity have led to the unanimous recommendation of Department engineers and consultants for construction of a single lift pumping system at the Tehachapi. Chief Engineer, Alfred R. Golze', has approved this recommendation finding that the most dependable system of pumping water the required 2000 feet will be by a single pumping plant at the base of the mountains instead of by one of the alternate proposals for a series of two or three pumping plants up the mountainside.

The Bechtel Corporation, who a few years ago, reviewed the Department's early studies and supported the single-lift scheme, has been employed as a consultant to the Metropolitan Water District of Southern California to make a separate analysis of the pump-lift problem. Bechtel's conclusions, which have been accepted by Metropolitan, favor a two-lift scheme, requiring a pumping plant and small reservoir half way up the mountain. The Department consultants and engineers have carefully reviewed the Bechtel studies and reports and find that they do not provide any basis to depart from the conclusion that the single-lift is the most reliable and safest of the several schemes.

Attached is a copy of the August 18 report of Chief Engineer, Alfred R. Golze' to me, describing the work of the Department in conducting this epic engineering program and his reasons for his decision in favor of the single-lift pumping scheme at the Tehachapi. The Engineers of the Department are to be commended on the excellent manner in which they approached and resolved this difficult problem.

William E. Warne

Director

APPROVED:

(sgd) Hugo Fisher

Administrator of Resources
State of California

AUG 26 1965

Date

Attachment

PHONE: ST. MICHAELS, MD.
RIVERVIEW 5-6025

JOHN R. HARDIN
Consulting Engineer
WITTMAN, MD.

September 10, 1965

Mr. Alfred R. Golze', Chief Engineer
Department of Water Resources
P. O. Box 388
Sacramento, California

Dear Mr. Golze':

Reference is made to:

a. My telegram dated August 13, 1965, stating the position of the Tehachapi Crossing Consulting Board.
b. Letter dated August 20, 1965, from Mr. J.A. Wineland and enclosures thereto pertaining to DMJM progress reports and the views of their Technical Advisory Board.
c. Your memorandum to the Director, Department of Water Resources, dated August 18, 1965, Subject: "Tehachapi Pump Lift System".

The members of the Tehachapi Crossing Consulting Board have reviewed the above listed material and their responses have now been received.

The additional material from DMJM has been noted with interest. It is the opinion of all Board members that this material is in consonance with our previous recommendation for a single lift scheme.

It is also our position that your memorandum dated August 18, 1965, addressed to the Director, is an excellent presentation of the facts leading to an unqualified recommendation on the selection of the single lift concept for the Tehachapi Crossing.

Yours very truly,

John R. Hardin

John R. Hardin
Chairman, Tehachapi Crossing
Consulting Board

September 27, 1965

Mr. Joseph Jensen
Chairman of the Board of Directors
The Metropolitan Water District of
Southern California
P. O. Box 54153, Terminal Annex
Los Angeles 54, California

Dear Joe:

This is in reply to your letter of August 27, 1965, on behalf of the Metropolitan Water District, asking that the State Department of Water Resources' decision to construct a single-lift pumping system for the Tehachapi Crossing of the California Aqueduct be, in effect, revoked and that final determination be deferred until at least May 1966. The purpose of the proposed delay would be to permit some additional testing of the State's pump models at another laboratory, the National Engineering Laboratory at East Kilbride in Scotland.

Your suggestion has been considered and I have come to the conclusion that neither the Department's decision nor its program for executing the decision should be altered or delayed. There is no doubt that either a one-lift or two-lift pumping system at the Tehachapis could be made to work. Thus we are not confronted with a choice between what is engineeringly feasible and non-feasible. The choice is between which <u>system</u>, not merely which <u>pump</u>, is better.

The choice as to system depends on considerations of probable seismic damage and operational reliability as well as on efficiency of pumps. Our Tehachapi Crossing Consulting Board states: "The two-lift scheme, having over twice the number of structures, offers twice the chance for seismic damage." The Board also found that the maximum simplicity of the layout of the single-lift "halves the problems and hazards of reservoir operation .... (minimizes) opportunity for human errors in operation .... and offers least opportunity for misoperation."

These manifest and irrefutable advantages of the single-lift could not be ignored even if there was significant differences between pumps designed for a single-lift and those designed for a two-lift. The Department has had pump models of both types tested at accurately calibrated laboratories in the manufacturer's plants in Europe. I am informed that no significant differences would be disclosed by testing the DWR models at the NEL facilities, compared to the results obtained at the manufacturer's plant laboratories. Accordingly, we and our technical consultants are confident that the results of the model tests conducted by the Department to date are more than adequate to support the decision made without waiting for any additional model tests to be conducted at NEL.

Results of the Department's comparative studies made for the two-lift and single-lift schemes, taking into consideration all of the efficiencies involved for all of the various features, have shown that there is little difference in the present worth of operating costs and total costs for either scheme. The Bechtel Corporation reached the same conclusion in its report to you of July 1965. Even assuming there were minor changes in model efficiencies resulting from the NEL testing program which you propose, there would be no material change in the system evaluation.

What is important to me is that a delay of the decision on the lift system until May 1966 or later would make it impossible to meet our commitment to deliver water into Castaic Reservoir in 1971 and Perris in 1972. The final designs which have been in progress by the Department for the single-lift are being expedited so that the first contracts for excavation at the pumping plant and for tunnels for the discharge lines can be advertised by January 1966, and specifications for the pumps be completed by the same date. Our designers are working on a six-day week to meet these dates and to overcome the delays already experienced in selecting the lift system. Nothing would be gained from parallel designs of two-lift systems as you suggest. The construction work for a single-lift system must be started well in advance of May 1966 and this work differs materially from that for a two-lift system. These differences do not permit any initial construction work for the one system to be made applicable to the other.

Furthermore, deferring the decision into 1966 as you propose would also jeopardize delivery of water from the California Aqueduct in the South San Joaquin Valley. It would require us to stop our design work at the Wind Gap, Wheeler Ridge and Buena Vista Pumping Plants, since the selection of the pumps at the Tehachapi plant governs the sizing of these upstream plants. As a matter of fact, an excavation contract for the Buena Vista Plant has been awarded and designs are essentially complete for the contracts for excavation at the Wind Gap and Wheeler Ridge plants to be advertised in January 1966, all based on pumps for a single-lift at the Tehachapis.

Thus your suggestion for delaying the choice in pumps is, perhaps unwittingly, a request that we abandon, not only on your behalf, but also on behalf of other water service contractors, the announced goal of water delivery by 1971. The modest gains, if any, to be achieved by further testing at NEL, do not warrant such a radical alteration of schedule. The urgent need for State water in the Valley and Southern California justifies only expediting our construction schedules, not their postponement.

I am satisfied that the Department and its consultants have taken every precaution in reaching our decision. All interested parties have been given ample time and study to consider the engineering, economic and related aspects of the Tehachapi crossing. The Department has certainly given the District thorough consideration of its views as required by Article 17(c) of our contract.

In summary, any further delay in choice of pumping lifts would impose the serious consequences of delaying water deliveries beyond dates to which we are committed and would not, in any event, yield any significant engineering information which could alter the decision that has been made. I must, therefore, decline to accept your suggestion.

Sincerely,

Edmund G. Brown

EDMUND G. BROWN, Governor

P.S.: If you want to see me, I will be happy to do so.

EGB

November 2, 1965

Mr. Joseph Jensen
Chairman of the Board of Directors
The Metropolitan Water District of
Southern California
P. O. Box 54153
Los Angeles, California 90054

Dear Joe:

It was indeed a pleasure to meet with you, members of your Board, your staff, and consultants on September 30, and to have you explain to me, personally, your thoughts on the Tehachapi Lift of the California Aqueduct. I know that the success of this great project is of vital concern, both to you of the Metropolitan Water District and to all other water contractors and potential water users south of the Tehachapi Mountains. At the same time, I want to assure you that the success of this venture is also of vital concern to me, personally, as Governor of the State of California.

At this meeting, I very carefully considered the positions put forth both by you and the Department of Water Resources in regard to this matter. Subsequently, I discussed the matter in great detail with the engineers and consultants of the Department of Water Resources. After this most thorough consideration I can find no reason to make any change in the course of action indicated in my letter to you of September 27, 1965. It is my firm conviction that the best interests of your District and of the State as a whole will be served by following this course of action.

In conclusion, I invite you and all of the Metropolitan Water District to cooperate in vigorously prosecuting the timely completion of the California Water Project so vitally needed by the people south of the Tehachapi Mountains. I can assure you that Mr. William E. Warne, Director of the Department of Water Resources, and his entire staff will cooperate to the fullest with you in this great endeavor.

Sincerely,

EDMUND G. BROWN, Governor

[illegible]